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Forwarded is the corrected copy of Table II for subject report. The table has been printed on gummed paper to be attached to the bottom of the page 21 with ease. Request that the copy (copies) of the report in your possession be corrected.

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Table II. Relative Course Severity^a at Maximum RMS - g (Regardless of

Test Courses	Wheeled				Track-Laying				
	M35	M37	XM125	XM410	M41	M56	M60	MT13	TT16
Paved	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Two-inch washboard	5.7	7.0	11.0	3.9	0.7	0.8	0.7	0.5	1.2
Six-inch washboard	3.0	3.6	1.5	5.9	0.9	0.9	0.7	0.5	1.2
Belgian block	3.1	3.0	3.0	2.3	0.7	0.9	0.7	0.8	1.2
Spaced bump	5.7	4.2	6.0	2.4	0.7	1.1	-	-	1.0
Six-inch ramp	3.0	5.5	4.0	2.5	0.6	0.4	0.7	0.4	0.4
Cross-country	1.0	1.6	1.5	0.91	0.4	0.3	0.6	0.2	0.4
Radial washboard	-	-	3.5	-	0.6	-	-	-	-

^aUsing paved road as base; (i.e., severity of paved road = 1.0).

- = Not measured, course under repair at time of test.

From a relative-severity viewpoint, the paved course creates the most severe environment for a track-laying vehicle while the 2-inch washboard course is generally the most severe for a wheeled vehicle. Again, this

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AUTOMOTIVE ENGINEERING LABORATORIES

REPORT ON

ROAD SHOCK AND VIBRATION ENVIRONMENT

FOR A SERIES OF WHEELED AND

TRACK-LAYING VEHICLES

by

H. T. CLINE

Report No. DPS-999

JUNE 1963



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ROAD SHOCK AND VIBRATION ENVIRONMENT FOR A SERIES
OF WHEELED AND TRACK-LAYING VEHICLES

Report No. DPS-999

Dates of Study: March - June 1963

ABSTRACT

The road shock and vibration environment created by four wheeled and five track-laying vehicles was measured on eight test courses at speed increments of approximately 4 mph. The magnetic-tape data were processed through a special-purpose computer which determined the amplitude-probability distribution and spectral density. The resultant data have been catalogued in a form which will provide a base line for the design of equipment to be transported on automotive vehicles.

CONTENTS

	<u>PAGE</u>
INTRODUCTION	3
RESULTS OF THE INVESTIGATION	7
TEST COURSE SEVERITY	21
DISCUSSION	22
FUTURE CONSIDERATIONS	22
CONCLUSION	23
LIST OF FIGURES	25
APPENDIX A: VIBRATION AMPLITUDE AND MAJOR FREQUENCIES	A-1
APPENDIX B: THE VIBRATION SPECTRUM	B-1
APPENDIX C: COURSE PROFILES AND INSTRUMENTATION DIAGRAMS	C-1
APPENDIX D: REPORT NO. DPS-657	D-1
APPENDIX E: DISTRIBUTION	E-1

1. INTRODUCTION

The objective of this report is to catalog the vibration environment of military wheeled and track-laying vehicles operating over natural and man-made land surfaces and profiles.

The Automotive Engineering Laboratory receives numerous requests for descriptions of automotive vehicle vibrational environments. These requests are invariably from designers, dynamists, or those charged with establishing design criteria for sensitive gear which may be transported on automotive vehicles. While limited data have been available for some vehicles under some conditions, the descriptions have never been complete nor has there been a standardized method of describing the environment.

For the past two years, this laboratory has concentrated efforts to obtain the hardware and develop the techniques and procedures for more complete data reduction and standardized presentation. The first product of this effort is contained in Appendix D which describes the basic method of codifying vibrational amplitudes of automotive vehicles.

In this report, the method of codifying amplitudes is applied to measurements made on a variety of vehicles over a range of comparable road speeds on several course profiles. In addition to amplitude, frequency is treated in the form of spectral analysis. The user of these data should consider them as a point of departure, a point from which he may go up or down in relative severity depending on his appraisal of how his design will be used in the field.

The nine different model vehicles and test courses used in the investigation are listed in Table I and shown in Figures 1 and 2. Four were wheeled vehicles and five were track-laying vehicles. On the five track-layers, three basic track designs were employed; the band type track, the single-pin block track, and the double-pin block track.

Table I. Vehicles Used in Investigation

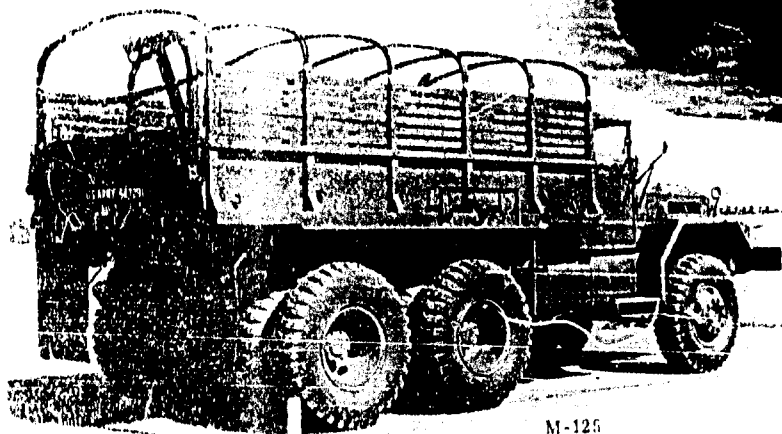
Vehicles	Gross Weights as Tested, lb
Truck, cargo, 3/4 ton, 4x4, M37	7500
Truck, cargo, 2-1/2 ton, 6x6, M35	17500
Truck, cargo, 2-1/2 ton, 8x8, M410	13750
Truck, cargo, 10-ton, 6x6, M125	52000
Carrier, personnel, T116	10500
Carriage, gun motor, M56	15000
Carrier, armored, personnel, M113	23000
Tank, 90-mm gun, M41	52000
Tank, main battle, 105-mm gun, M60	103000



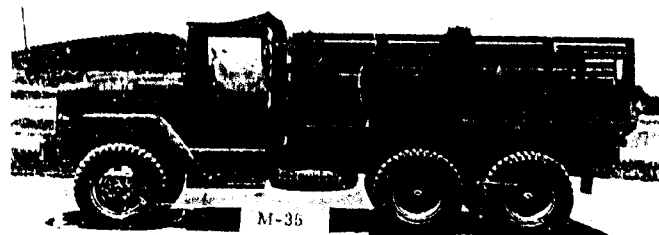
M-37



M-410



M-125



M-35

Figure 1: Wheeled Vehicles Used in the Investigation.

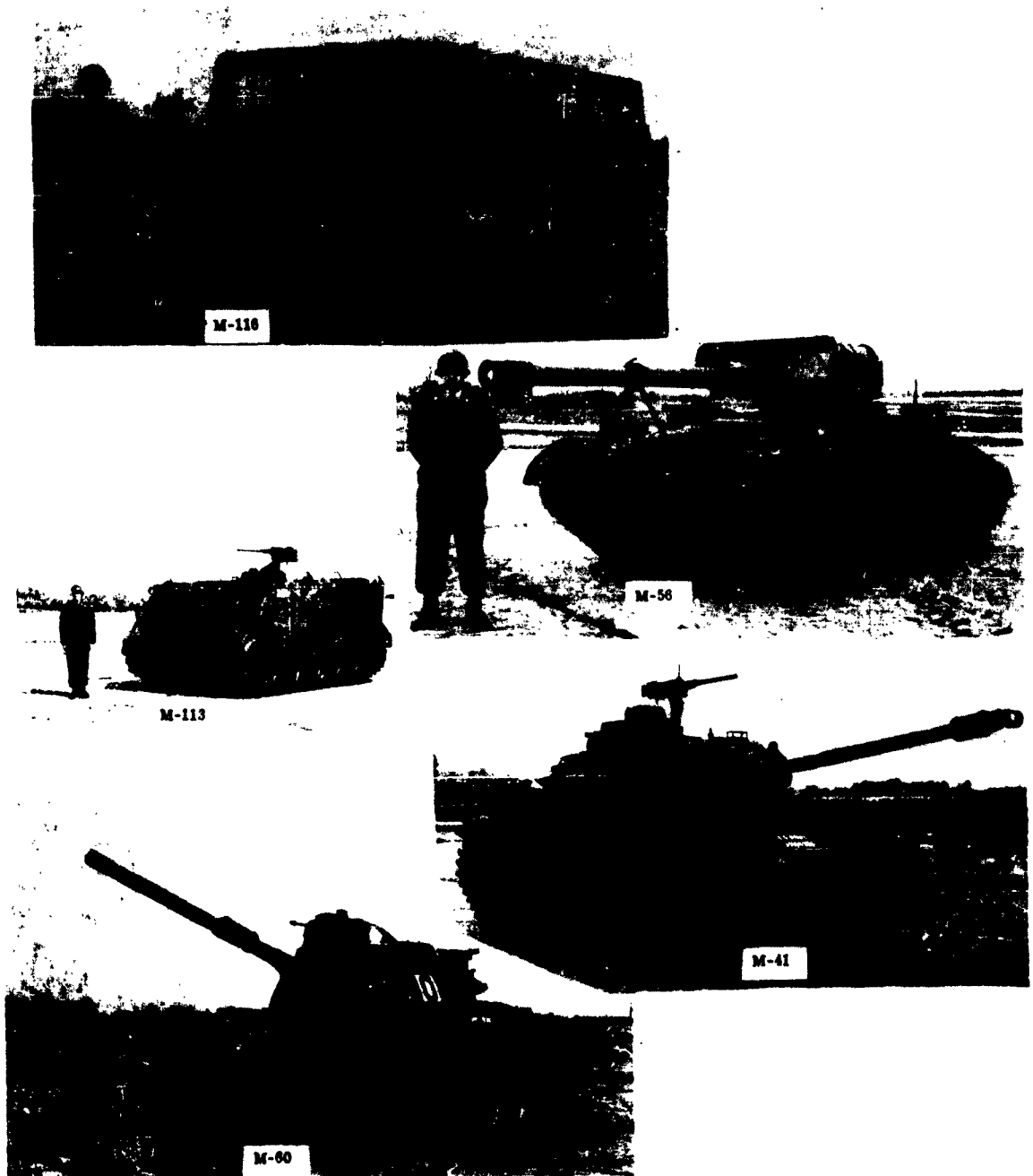


Figure 2: Track-Laying Vehicles Used in the Investigation.

All vehicles were carrying their rated payload or were loaded to their rated gross vehicle weight. Tires on wheeled vehicles were inflated to rated pressures.

These vehicles were operated over eight different test courses at various increments of road speed. The test courses were as follows:

- Six-inch washboard
- Two-inch washboard
- Belgian block
- Spaced bump
- Radial washboard
- A section of cross-country
- Six-inch ramp
- Paved (bituminous concrete)

Profiles of these courses are shown in Appendix C.

Data were acquired from unbonded, strain-gage accelerometers mounted at approximately the same locations on each vehicle (Appendix C). The output of the accelerometers were recorded on multi-channel magnetic tape. Tape recorders were installed in an instrument van which operated on the smooth road paralleling the various test courses and paced the vehicle under test. As may be seen in Figure 3, transducers were coupled to the tape recorders by means of 100-foot cables suspended between the two vehicles.

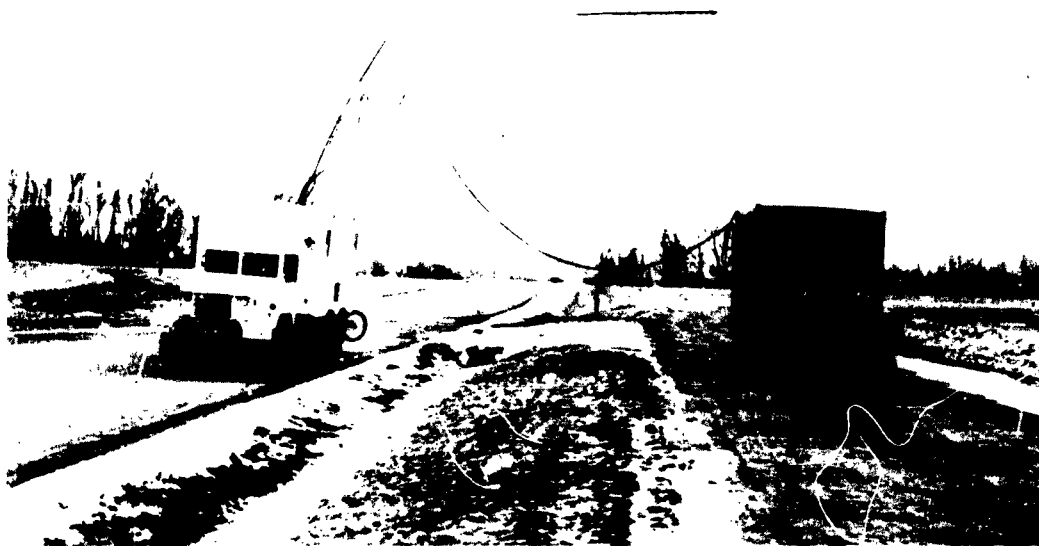


Figure 3: Typical Method of Data Acquisition. (Vehicle under Test Is Not One of the Nine Vehicles Comprising This Investigation.)

In the laboratory, the data acquired in the field were transcribed from the reel onto tape loops. The signals on the tape loops were then reproduced continuously and fed to a multi-channel special-purpose automatic data processing

system (Figure 4). The data were processed in two ways; amplitude distribution of acceleration and spectral analysis to determine the density of amplitudes over the frequency spectrum using pass-band filters. The amplitude-distribution-analyzer portion of the system and the procedures, which were designed to fulfill the needs of this laboratory are described in Appendix D. The six spectrum analyzers in the system were built by the Ortholog Division of Gulton Industries and are designated model OR-WA/SY6.



Figure 4: Automatic Data-Processing System.

2. RESULTS OF THE INVESTIGATION

Data cataloged are for response in the vertical plane only since it describes the higher level of response. Measurements were made in both the longitudinal and transverse planes but were not found to be sufficiently different from the vertical to warrant separate treatment.

2.1 Amplitude Severity

Full frequency-spectrum^a amplitude-distribution analysis were determined for about 850 data samples collected at various locations on the nine vehicles over the courses at various road speeds. Each of the samples analyzed was of adequate time duration to provide a stationary process for the vehicle-course-speed combination. Results of these analyses again confirmed that the distribution of the amplitude is not necessarily Gaussian. Consequently, the amplitude-probability distribution for maximum response on the cargo bed of each vehicle for each course at each speed are plotted as three values in Appendix A. These three values are the rms amplitude level, the amplitude level exceeded 1% of the time, and the approximate crest or maximum amplitude. From these values, the reader may interpret the distributions for his particular purpose. It may be noted that the ratios of crest to rms range from about 3 to 15 for individual conditions.

^aThe frequency spectrum for data in this report is considered 0 to about 270 cps as limited by flat response of Statham Laboratories ± 25 g accelerometers, model A5.

2.2 Response of Cargo Bed of Wheeled Vehicles

Since the rms amplitude has been previously established and defined as relative severity (Appendix D) it is used here in that one term of reference. Considering that the reader wishes to arrive at the composite picture of wheeled-vehicle response, envelopes drawn over the maximum rms and 1% time level on the cargo beds of each of the four vehicles at the various comparable test speeds, regardless of the course, are shown in Figures 5 and 6, respectively. This comparison is based on a one-vehicle-per-type sample and shows that the relative-severity level can be as high as 2 g rms and the 1% time level can be as high as 6 g for the 4x4 and 6x6 wheeled vehicles. It further shows that the M410 vehicle with independent wheel suspension (torsion bar) for the 8x8 wheel arrangement provides a relative amplitude severity which is significantly less than that created by the 4x4 and 6x6 vehicles regardless of weight class.

2.3 Response of Track-Laying-Vehicle Hull

Again, based on a single-vehicle sample for each of the five models, envelopes drawn over the maximum rms values and 1% time levels measured on the vehicle hull in the vertical plane at various road speeds, regardless of test course, are plotted in Figures 7 and 8, respectively.

These plots show the amplitude environment created by the M116 personnel carrier to be significantly more severe than the other track-laying vehicles. That of the M60 main battle tank appears to be the least severe. In this case, the M116 represents the lightest, and the M60 the heaviest, of the five vehicles tested.

2.4 Factors Affecting the Amplitude Severity of Some Track-Laying Vehicles

Additional work conducted on an M113 armored personnel carrier, which was not part of the nine-vehicle test, disclosed some factors which affect the amplitude severity of this vehicle. These factors were track tension and the general condition of the vehicle with respect to the amount of wear on the running gear (i.e., track pads, track blocks, sprockets, road-wheel tires and shock absorbers). Results of tests on two M113 vehicles, one relatively new and one well used, are shown in Figure 9. Both vehicles were run at five different degrees of track tension, measured by the relative amount of sag, ranging from a very loose track, which could conceivably have been thrown in mud or adverse terrain, to a very tight track which noticeably affected the rate of acceleration in road speed. The hatched areas on Figure 9 show the range of severity from loose to tight tension for each vehicle. Intermediate tensions fell in logical sequence within these bands. It was also noted during these related tests that the severity level measured on one side of the vehicle could be much greater than that on the other side for a given nominal track tension. There was no consistency as to which side responded with maximum severity at the various track tensions.

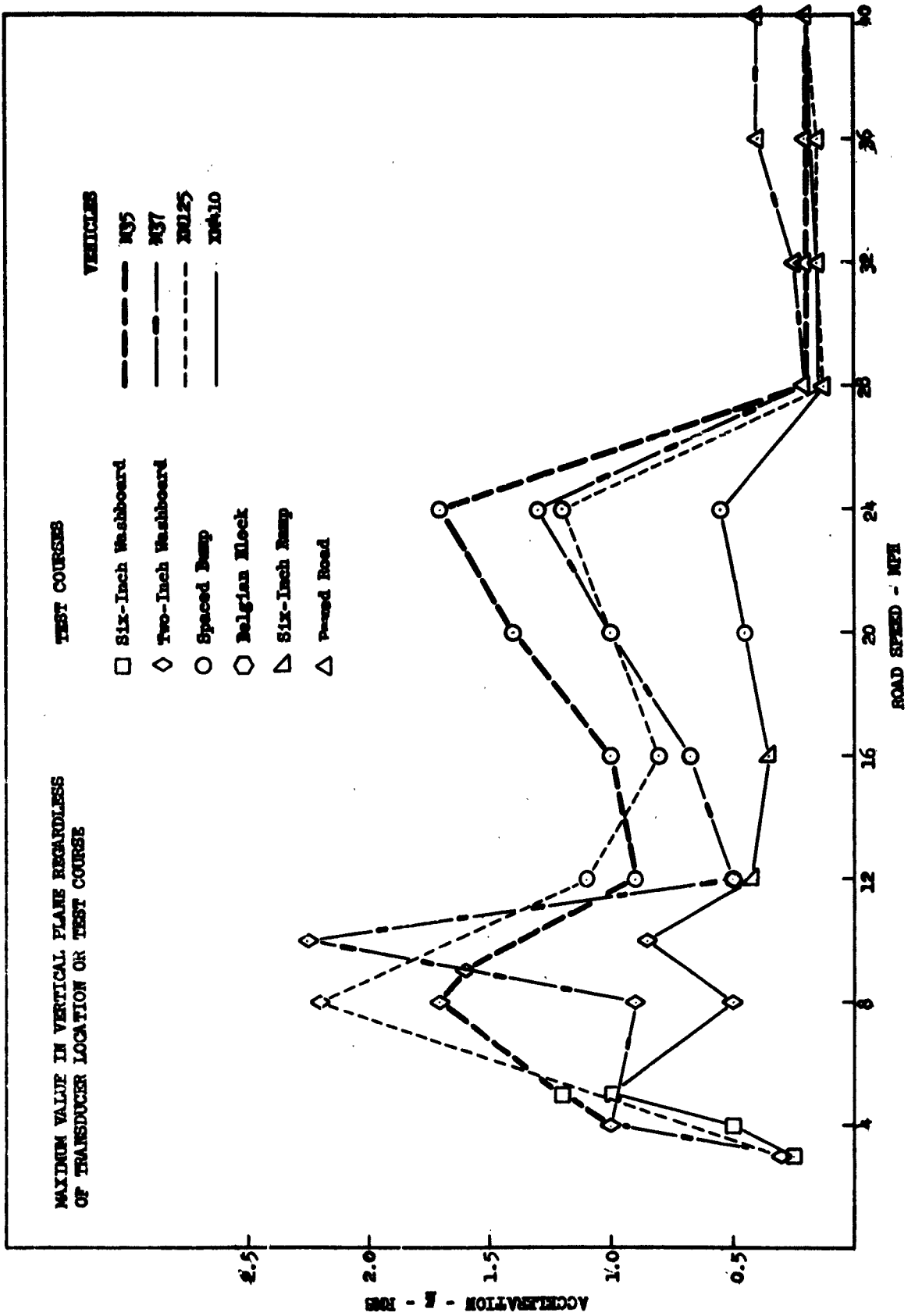


Figure 5: Comparison of Severity of Vibration on Cargo Bed for Four Different Wheeled Vehicles.

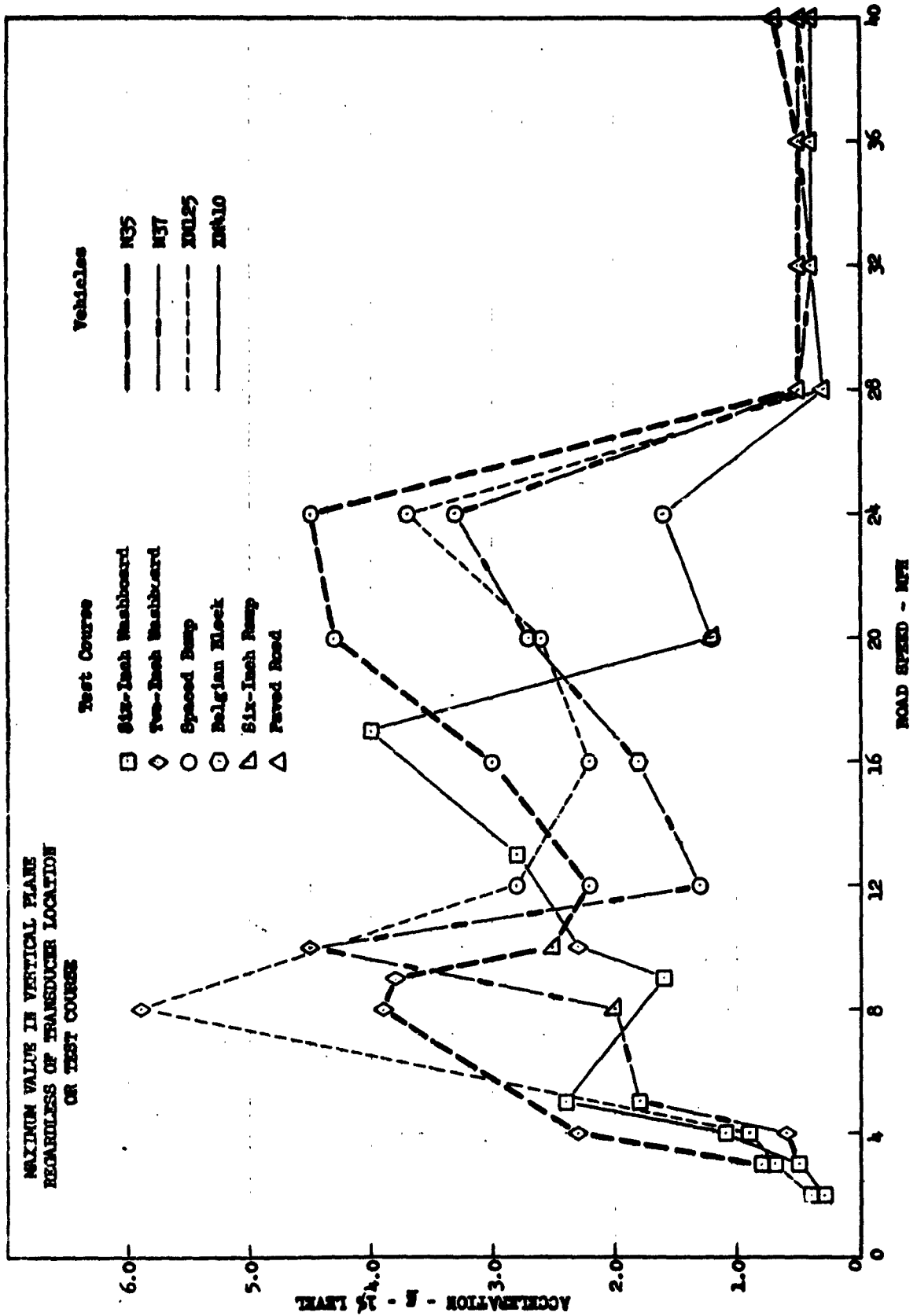


Figure 6: Comparison of Vibration Levels Exceeding 1% of Time on Four Different Wheeled Vehicles.

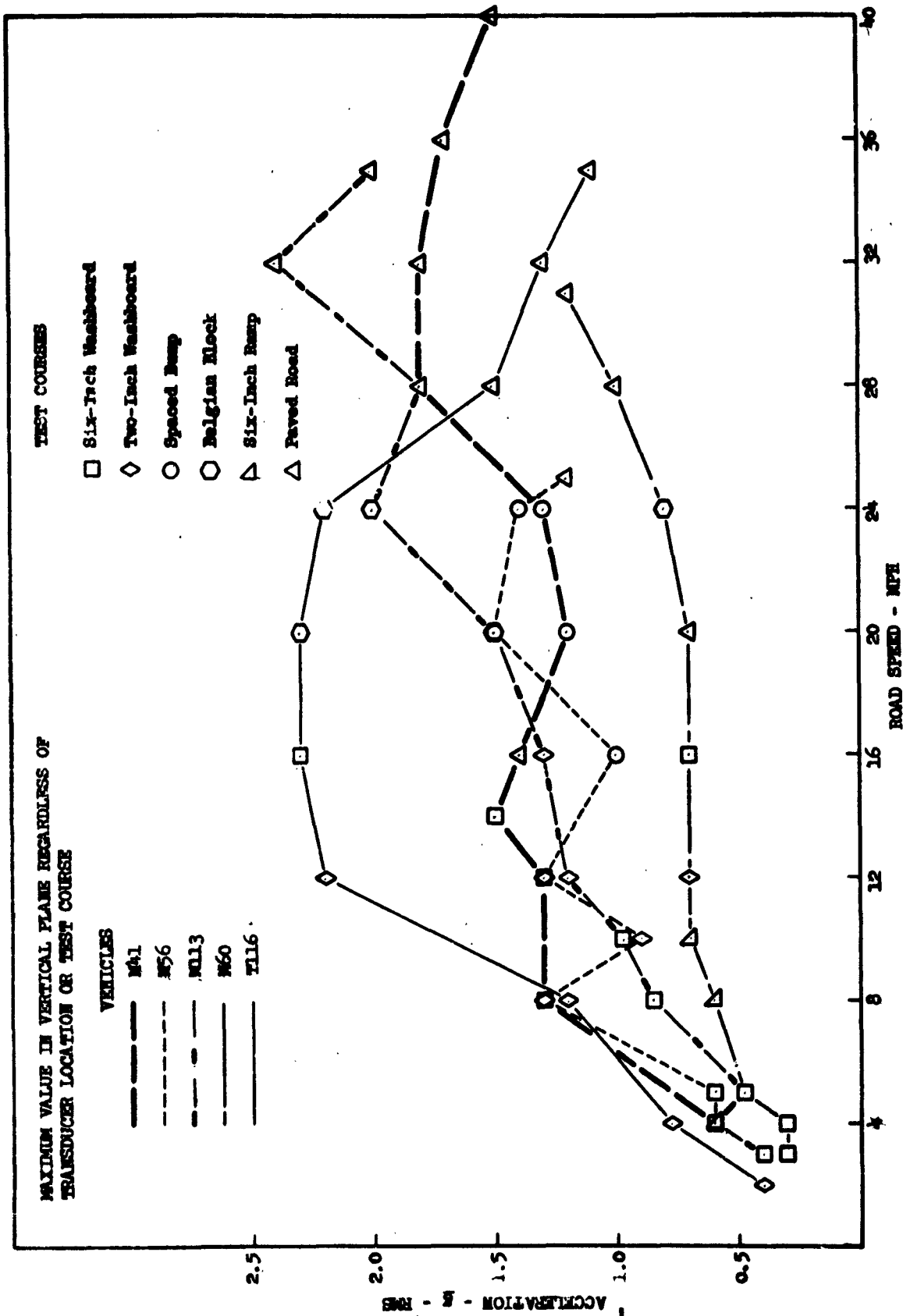


Figure 7: Comparison of Severity of Vibration on Vehicle Hull of Five Different Track-Laying Vehicles.

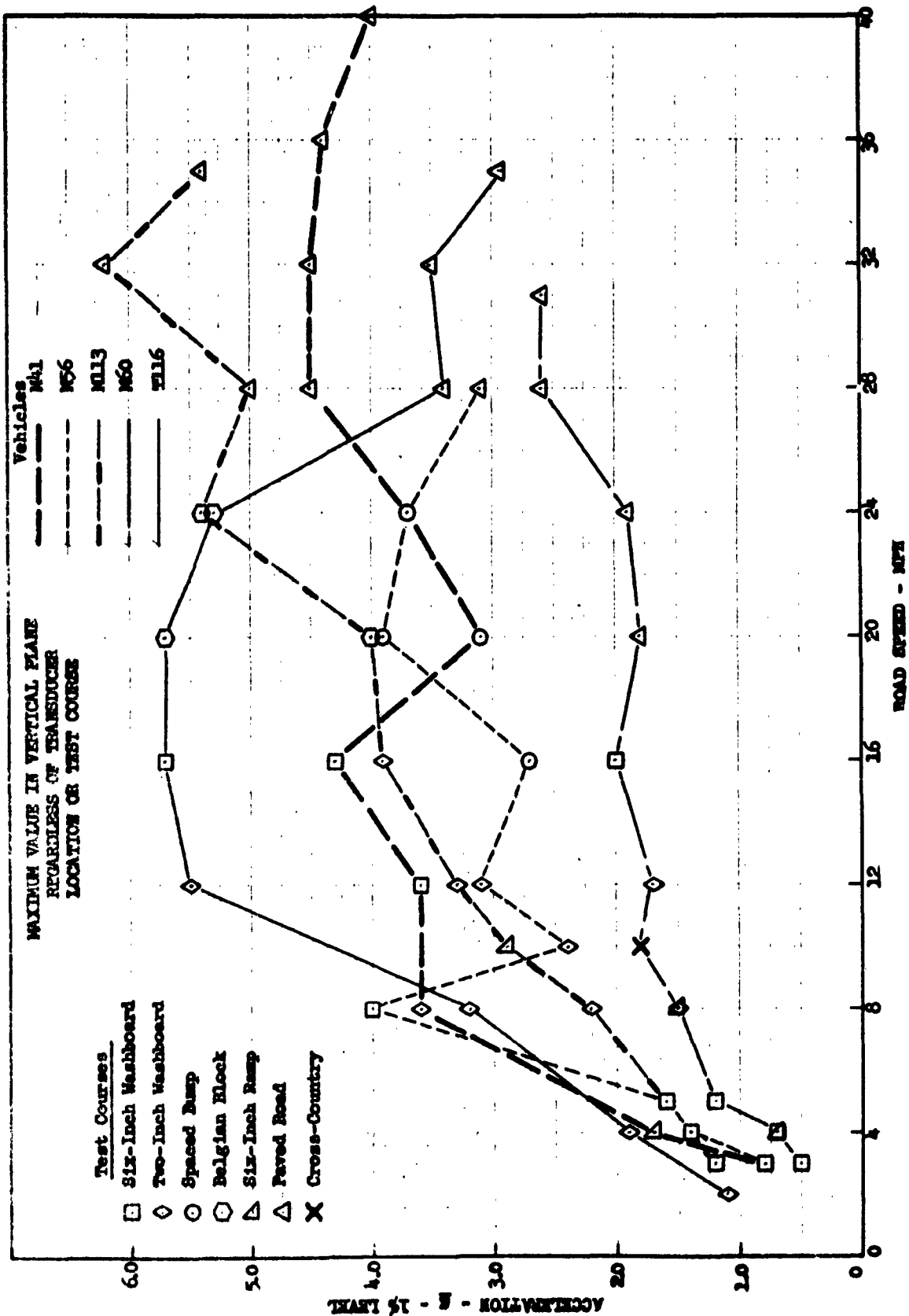


Figure 8: Comparison of Vibration Level Exceeded 1% of Time on Five Different Track-Laying Vehicles.

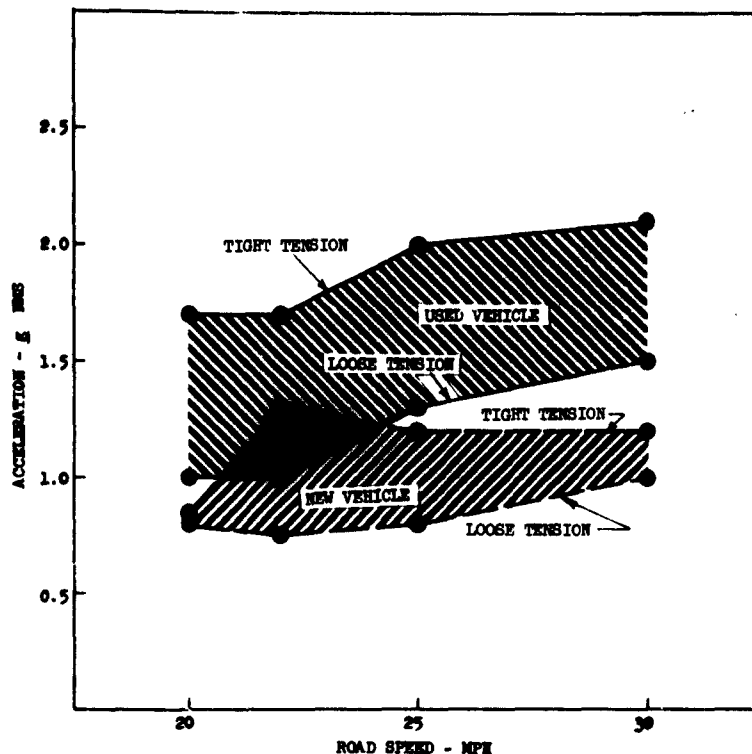


Figure 9: Comparison of Vibration Severity in Vertical Plane of New and Used Armored Personnel Carriers, M113, at Various Track Tensions.

Based on these data, it appears that:

- a. The method of measuring and adjusting track tension is not precise; but even though it were, the tension changes with continued operation.
- b. Although the severity for any vehicle condition, nominal track tension and vehicle road speed combination is a stationary process, the effect of different vehicle and tension combinations on severity is so broad as to preclude precise comparisons between vehicles. It should be noted that the only M113 available for the nine vehicle test was a well used vehicle. The severity level for the M113 plotted on Figure 7 lies within the envelope plotted for the well used vehicle on Figure 9.

2.5 Shock

The term shock, as used in this report, is defined in Appendix D. A review of crest values in Appendix A shows values as high as about 12 g's on both wheeled-vehicle cargo beds and track-laying vehicle hulls. On wheeled vehicles, shock may result from suspension bottoming or impacting between the front of the cargo bed and the vehicle frame. Impacting can occur at the front of the cargo bed on long-wheel-base vehicles because of the necessity of some freedom between

the rigid cargo bed and the flexible frame. A displacement gage mounted on an M35 truck (Figure 10) indicated about 3/8-inch displacement between the bed and the frame on the spaced bump course and this course does not produce noticeable torsional motion in the frame. Shock for track-laying vehicles is usually occasioned by bottoming of the suspension. One considering the environment for the transportation of sensitive gear should recognize that the 12 g shocks represent the input to the sensitive gear by the cargo bed. If the gear is properly restrained to move with the cargo bed, input to the gear should not be amplified. If the gear is poorly secured or loose, accelerations of 1 g and greater will cause relative displacement between the gear and the bed with a resultant impact. Shock levels generated by such impacting cannot be predicted with any degree of accuracy.

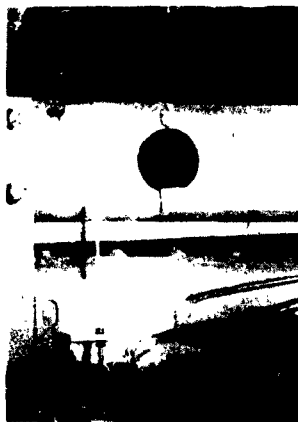


Figure 10: Displacement Gage As Mounted between the Bed and Frame of an M35 Truck.

2.6 The Frequency Spectrum for Vehicles

A comparison of the frequency spectrums for wheeled and track-laying vehicles shows no basic similarity between these two general classes of vehicles. Within each class of vehicles the frequency spectrums exhibit similar characteristics. The general spectrum for wheeled vehicles is shown in Figure 11. The spectrum is based on envelopes drawn over values extracted from spectral density analysis of recordings made at various road speeds on various test courses (Appendix B). For wheeled vehicles, each analysis was made using a 2.5 cps bandwidth filter. Maximum amplitudes for any 2.5 cps bandwidth quasi-discrete frequency or broader random frequency were extracted and point-plotted as the center of the quasi-discrete, or random, frequency. An envelope drawn over the maximum point is intended to show the relative shape of the spectrum. The y axis (amplitude) of the plots are assessed in terms of g^2/cps . For wheeled vehicles (Figure 11) the spectrum generally ranges from 1 to 50 cps. Natural and forced suspension frequencies with their harmonics account for vibration in the 1 to 10 cps range. Tire frequencies and vehicle-frame frequencies are generally in the range from 10 to 40 cps. Vibrations of significant magnitude at higher frequencies are seldom present.

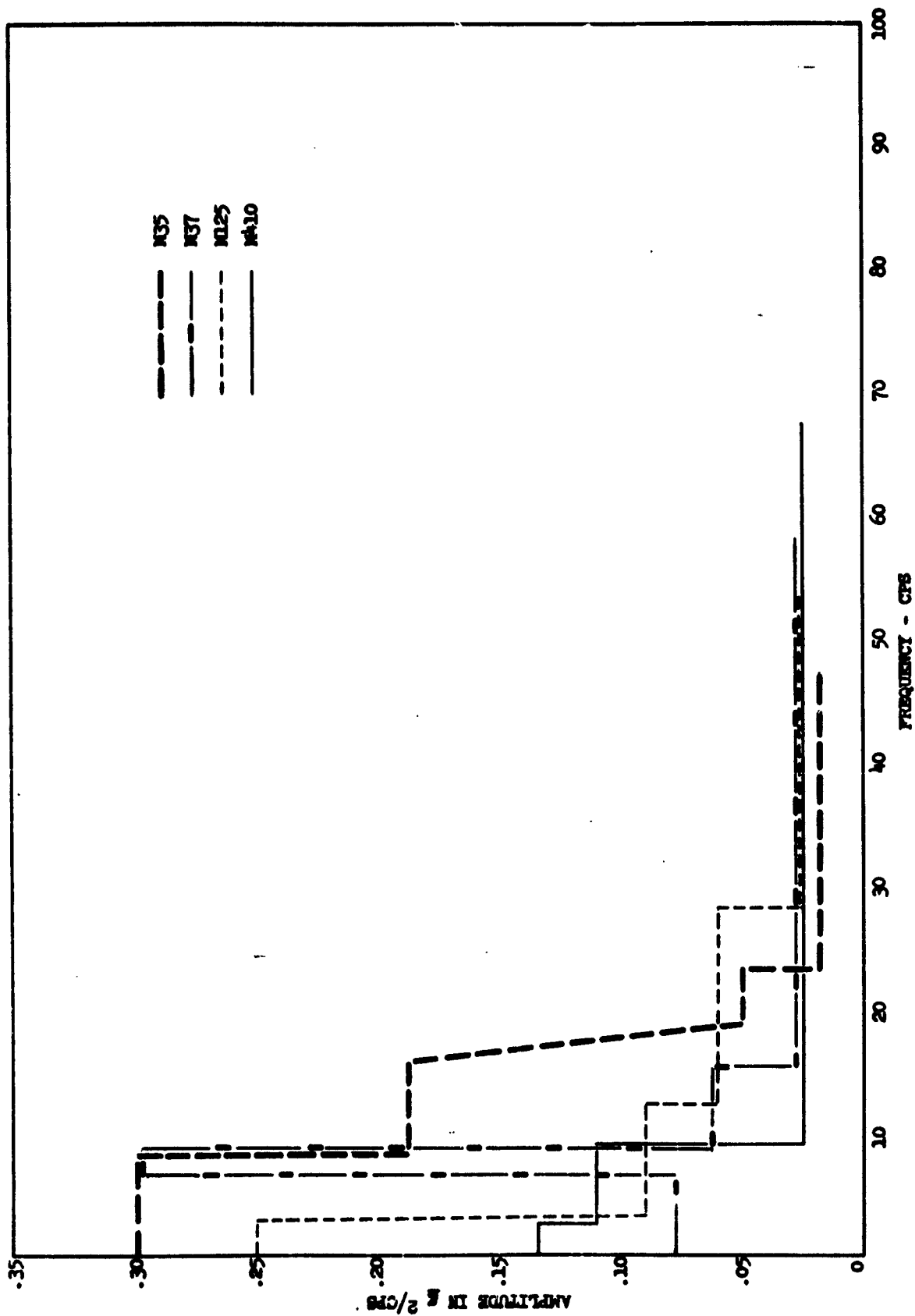


Figure 11: Spectral Envelope for Wheeled Vehicles Based on Data Extracted

The frequency-spectrum configurations for track-laying vehicles are shown in Figure 12. This graph was constructed in the same manner as Figure 11. The analysis was made using a 2.5 cps bandwidth filter.

Frequencies for track-laying vehicles appear to come from two prime sources; the suspension and the track. Suspension frequencies range from 1 to 10 cps and are directly associated with the natural frequencies of the suspensions, their harmonics, and the forcing frequencies of the course profiles at the various road speeds. Track frequencies (f_t) are directly related to track pitch and road speed and may be expressed as:

$$f_t = \frac{kv}{p}$$

where k = constant = 1.47 ft/sec/mph
 v = velocity mph
 p = track pitch ft

The M60, M41, and M113 vehicles are equipped with 6-inch-pitch, rubber-bushed tracks while the M56 and T113 vehicles are equipped with band-type tracks having a 4-inch pitch. Examination of the track and suspension indicates that there may be several input sources; i.e., the engagement of track and sprocket, engagement and disengagement of track with the road and the road wheels passing over the track blocks. At a given road speed, each of these phenomena occur at the same rate of repetition but not necessarily at the same instant in time.

The engine of a vehicle is usually recognized as a potential source of vehicle vibration. Experiments conducted by operating the engine of the M113 over its speed range with the transmission in neutral gear showed that engine vibrations transmitted to the vehicle hull, measured by the ± 25 g transducers, were masked by the background noise on the tape as the tape recorder has a signal-to-noise ratio of 40 db.

2.7 The Driver as a Dynamic-Response Governor

On wheeled vehicles in particular, the driver is perhaps the best means of regulating or limiting the magnitude of response. This may be shown in part by detailed analysis of data acquired for the M35 truck. The envelopes of severity (full spectrum rms) for the cargo bed and the base of the driver's seat are compared in Figure 13. In general, the seat-base severity is less than that of the cargo bed because the driver's position between the wheels protect him from the vertical components of angular acceleration caused by the pitching of the vehicle. It has been established that the natural frequency of humans is near 5 cps and that the chest will not respond at frequencies greater than 20 cps. Consequently, the probability-distribution functions of data acquired at the base of the driver's seat were determined through filters and are plotted in Figure 14. This shows that amplitudes with associated frequencies in the range of 0.2 to 10 cps are almost the sole contributor to the severity level which has a maximum of about 0.6 g rms. Results of spectral analysis of response measured at the driver's chest, regardless of course or speed, are compared with human comfort limits in Figure 15. It may be seen

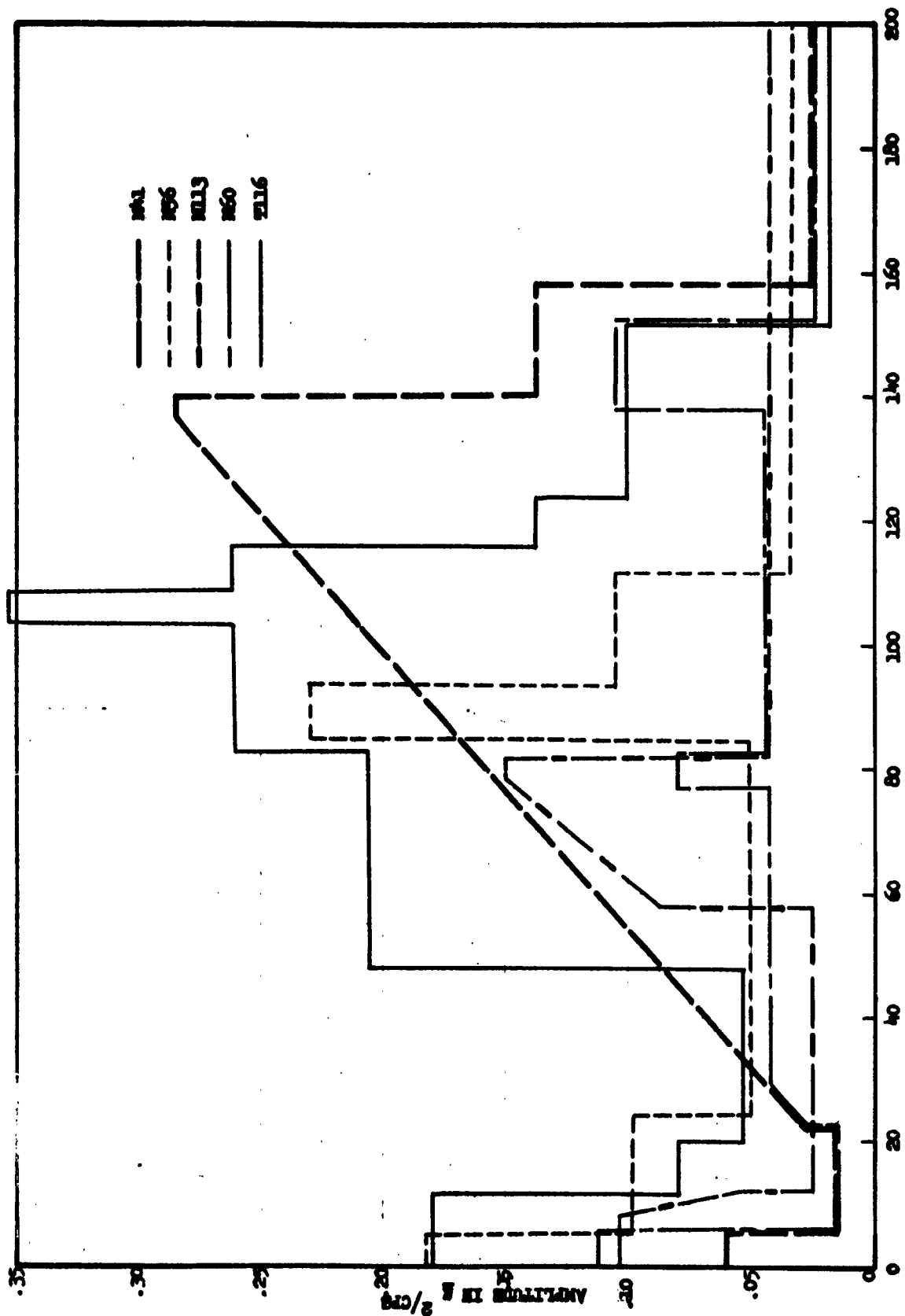


Figure 12: Spectral Envelope for Track-Laying Vehicles Based on Data
Extracted from Appendix B.

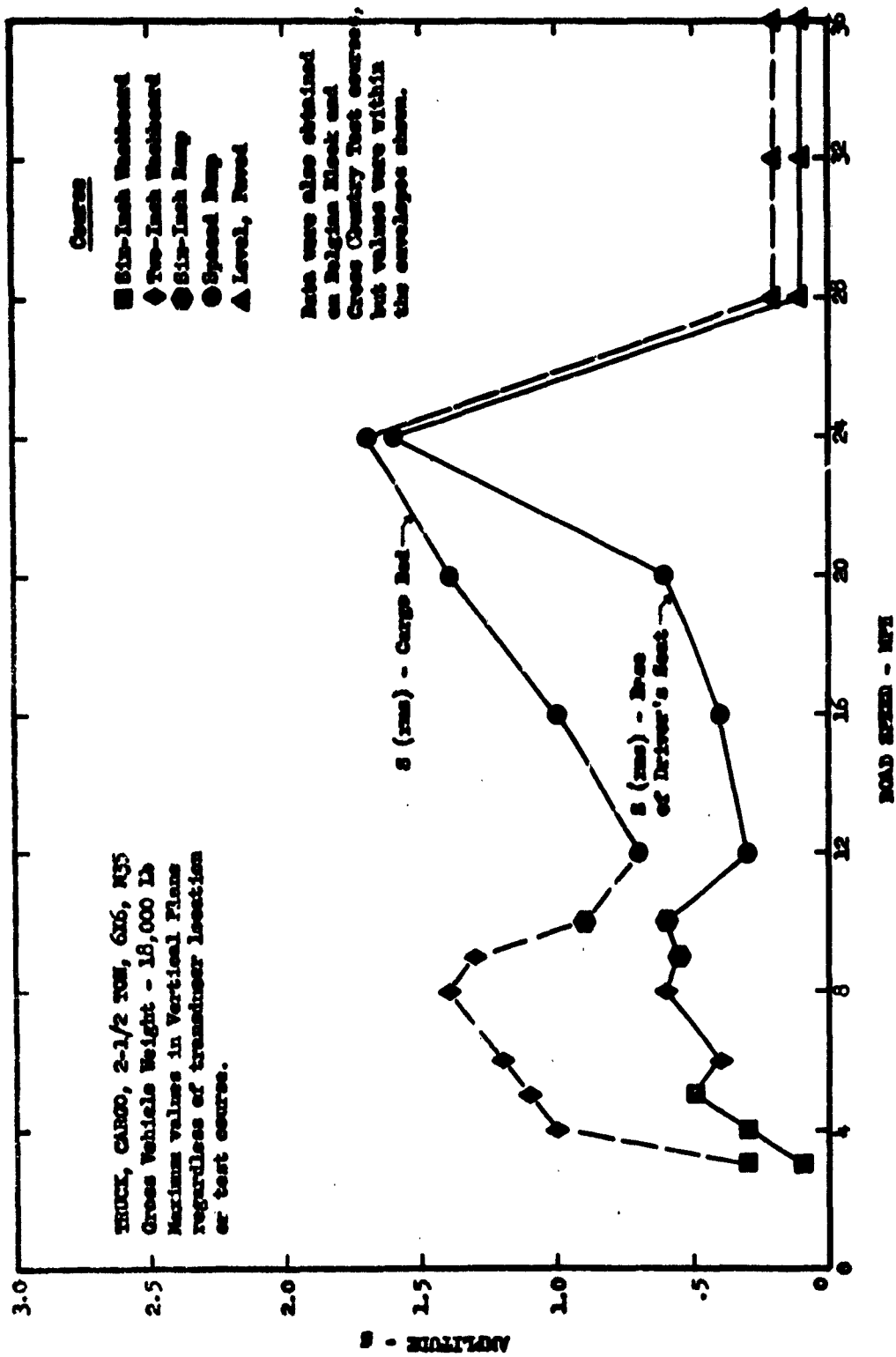


Figure 13: Root Mean Square Vibration Environment for Cargo Bed and Base of Driver's Seat.

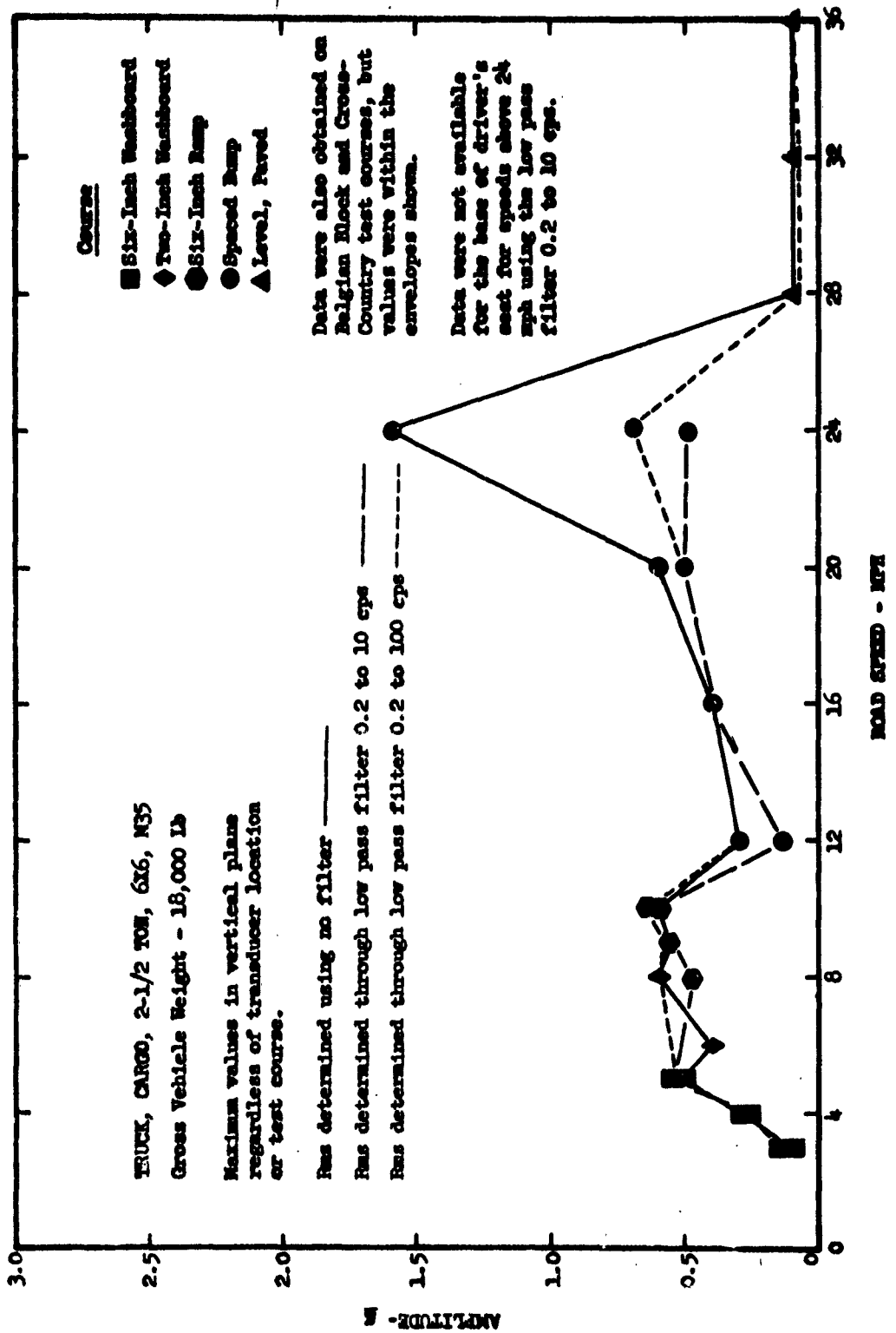


Figure 14: Root Mean Square Vibration Environment for Base of Driver's Seat.

that the maximum values measured as inputs to the driver's seat (Figure 14) approaches or exceeds the limits subjectively established as being extremely uncomfortable. The response of the driver's chest (Figure 15) shows amplification over the input. Although 0.6 g is extremely uncomfortable and accelerations of 1 g or more will cause a human to leave the seat, a driver will tolerate this for periods of a minute or two for testing purposes. If allowed to select speeds on the various courses which must be sustained for long periods of time, the driver will undoubtedly select one which creates a more comfortable environment. This desire to avoid discomfort effectively governs the response of the cargo bed.

While the same rules apply to track-laying vehicles, they must be tempered with certain undeniable considerations. When driving a track-layer (M113, M60, and M41) with the hatches buttoned up, the driver is restricted to a sitting position on the seat and the response of the seat is the input to the driver. If the driver is permitted to drive with the hatch open, he need not sit on the seat. At the approach of rough terrain, he may assume a semicrouched posture and use his legs as shock absorbers. In this manner, he may withstand greater acceleration inputs with very little discomfort than when he is restricted to the seat.

3. TEST COURSE SEVERITY

The question is often asked, "What is the relative severity of the different test courses?" Previously, the question could be answered only on the basis of subjective feeling. Now, the method of codifying amplitude distribution (Appendix D) provides an approach to quantitative description. The maximum relative severity of each test course compared to a smooth paved road is listed in Table II.

Table II. Relative Course Severity^a at Maximum RMS - g (Regardless of Speed)

Test Courses	Wheeled				Track-Laying				
	M35	M37	XM125	XM410	M41	M56	M60	M113	T116
Paved	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Two-inch washboard	4.7	5.5	6.0	4.5	0.67	0.69	0.53	0.50	1.1
Six-inch washboard	1.7	1.2	1.4	2.1	0.89	0.69	0.60	0.42	1.1
Belgian block	2.7	2.5	2.2	2.4	0.67	0.69	0.60	0.67	1.5
Spaced bump	5.3	3.7	4.6	2.9	0.72	0.78	-	-	1.2
Six-inch ramp	2.6	4.2	3.4	2.5	-	0.28	0.53	0.32	0.39
Cross-country	0.77	1.3	1.0	0.81	0.39	0.11	0.47	0.20	0.38
Radial washboard	-	-	2.5	-	0.61	-	-	-	-

^aUsing paved road as base; (i.e., severity of paved road = 1.0).

- = Not measured, course under repair at time of test.

From a relative-severity viewpoint, the paved course creates the most severe environment for a track-laying vehicle while the 2-inch washboard course is generally the most severe for a wheeled vehicle. Again, this

comparison is based on the maximum rms measured on each course regardless of speed. The rms, 1%, and crest levels contained in Appendix A allow the reader to make other comparisons he may desire.

4. DISCUSSION

There is no known, universally accepted, method of presenting shock and vibration data for automotive vehicles. Neither is there a known, universally accepted, method of applying existing data to general design problems. The ability to bridge the gap between testing and design appears almost impossible with available lines of communication. Consequently, the methods of presenting the data contained in this report were devised by the Automotive Engineering Laboratory. The methods are intended to provide the maximum available information for the individual user and not to formulate the manner in which he must use it. From an amplitude viewpoint for example, the percentage of time any amplitude level was exceeded for any particular course or speed condition can be estimated from the plots contained in Appendix A and the distribution plot in Appendix D (Figure 4). It should be noted here that a testing agency cannot project the total amplitude - time environment to be experienced by some proposed or existing on-board gear since it has no idea of the type of terrain and the length of time over which the gear will be transported. This is a problem which can be resolved only by the designer and the user.

From a frequency viewpoint, the major frequencies noted for each particular course and speed condition are also tabulated on the plots in Appendix A. An indication of the amplitude of the more significant narrow-band responses are shown in Appendix B. The relative shape of the amplitude-frequency spectrum for the various vehicles have been previously described in Figures 11 and 12. These envelopes do not imply time. They do give the instantaneous psd value that can exist for the analysis bandwidth.

Shock has been defined in this report only in terms of amplitude. It has not been investigated in detail as to shape and time duration.

During the preparation of the various tables and plots for this report every effort has been made to avoid intentionally overemphasizing the environment to provide a safety factor. As previously stated, the speeds attained over the various courses were within the capability of the vehicle and were safe speeds with respect to vehicle stability. Some of the maximum speeds created environments which a driver will tolerate for short periods of time but which he will not sustain. To reiterate, the reader should consider these data as a point of departure; a point from which he may go up or down in relative severity depending on his appraisal of the intended field operation.

5. FUTURE CONSIDERATIONS

The wheeled vehicles cataloged in this report represent only the cargo-type vehicle. Another family of wheeled transporter in which there is considerable interest is the trailer.

Many types of trailers have been investigated in the past but unfortunately, they were not all run under comparable conditions of course, speed, transducer location, payload, and method of data reduction. Because of this, the data are not suitable for inclusion in this report. Description of the dynamic response of trailers is believed to be of such interest to warrant a separate program aimed specifically at cataloging the response of several typical configurations.

6. CONCLUSION

The automotive vehicular road shock and vibration environment has been cataloged in a form which will provide a base line for the design of equipment to be transported on these vehicles.

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LIST OF FIGURES

- FIG. 1 - Wheeled Vehicles Used in the Investigation
- FIG. 2 - Tracklaying Vehicle Used in the Investigation
- FIG. 3 - Typical Method of Data Acquisition
- FIG. 4 - Automatic Data Processing System
- FIG. 5 - Comparison of Severity of Vibration on Cargo Bed for Four Different Wheeled Vehicles
- FIG. 6 - Comparison of Vibration Levels Exceeded 1% of Time on Four Different Wheeled Vehicles
- FIG. 7 - Comparison of Severity of Vibration on Vehicle Hull of Five Different Tracklaying Vehicles
- FIG. 8 - Comparison of Vibration Level Exceeded 1% of Time on Five Different Tracklaying Vehicles
- FIG. 9 - Comparison of Vibration Severity in Vertical Plane of New and Used Armored Personnel Carriers M113 at Various Track Tensions
- FIG. 10 - Displacement Gage as Mounted on M35 Truck
- FIG. 11 - Spectral Envelope for Wheeled Vehicles
- FIG. 12 - Spectral Envelope for Tracklaying Vehicles
- FIG. 13 - Root Mean Square Vibration Environment for Cargo Bed and Base of Drivers Seat
- FIG. 14 - Root Mean Square Vibration Environment for Base of Drivers Seat
- FIG. 15 - Drivers Response Compared With Subjectively Established Human Reaction to Vertical Vibration

APPENDICES

	<u>PAGE</u>
APPENDIX A: VIBRATION AMPLITUDE AND MAJOR FREQUENCIES.....	A-1
APPENDIX B: THE VIBRATION SPECTRUM.....	B-1
APPENDIX C: COURSE PROFILES AND INSTRUMENTATION DIAGRAMS	C-1
APPENDIX D: REPORT NO. DPS-657	D-1
APPENDIX E: DISTRIBUTION	E-1

APPENDIX A

Vibration Amplitude and Major Frequencies

The vibration-amplitude environment (vertical) is plotted against road speed for each vehicle on each course giving rms, 1% level, and crest. The significant frequencies which make up the frequency spectrum for the different speeds are listed with arrows pointing to the respective rms value associated with the over-all spectrum. A significant frequency, as defined for this report, is a frequency which has an rms value of at least 0.1 g. Therefore, in listing the significant frequencies for a spectrum, it was noticed that some of them were very close together. These frequencies were listed separately because of the distinct definition between them. The purpose of listing these significant frequencies is to give the reader some indication as to where most of the energy or power in the spectrum lies. The frequency which appears to have the greatest amplitude is defined as a major frequency and is circled. Other than this, there is no indication of the relative magnitude of the individual narrow-band frequencies. If, however, the reader is interested in these magnitudes, the power-spectral density plots of each channel of data at each speed are on file in the Automotive Engineering Laboratory.

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

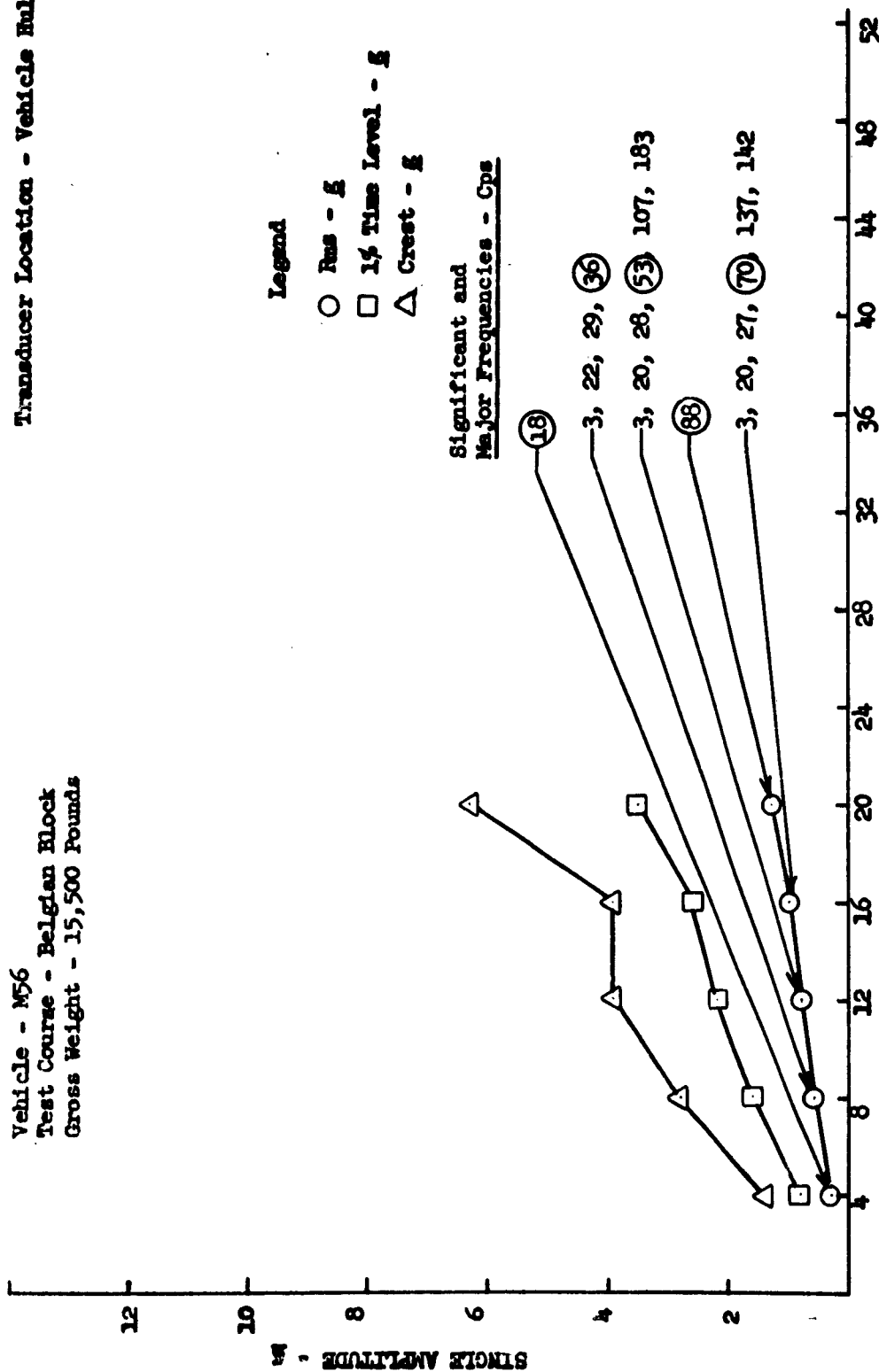
Vehicle - M56
Test Course - Belgian Block
Gross Weight - 15,500 Pounds

Transducer Location - Vehicle Roll

Legend

- Run - g
- 1/4 Time Level - g
- △ Crest - g

Significant and Major Frequencies - Cps



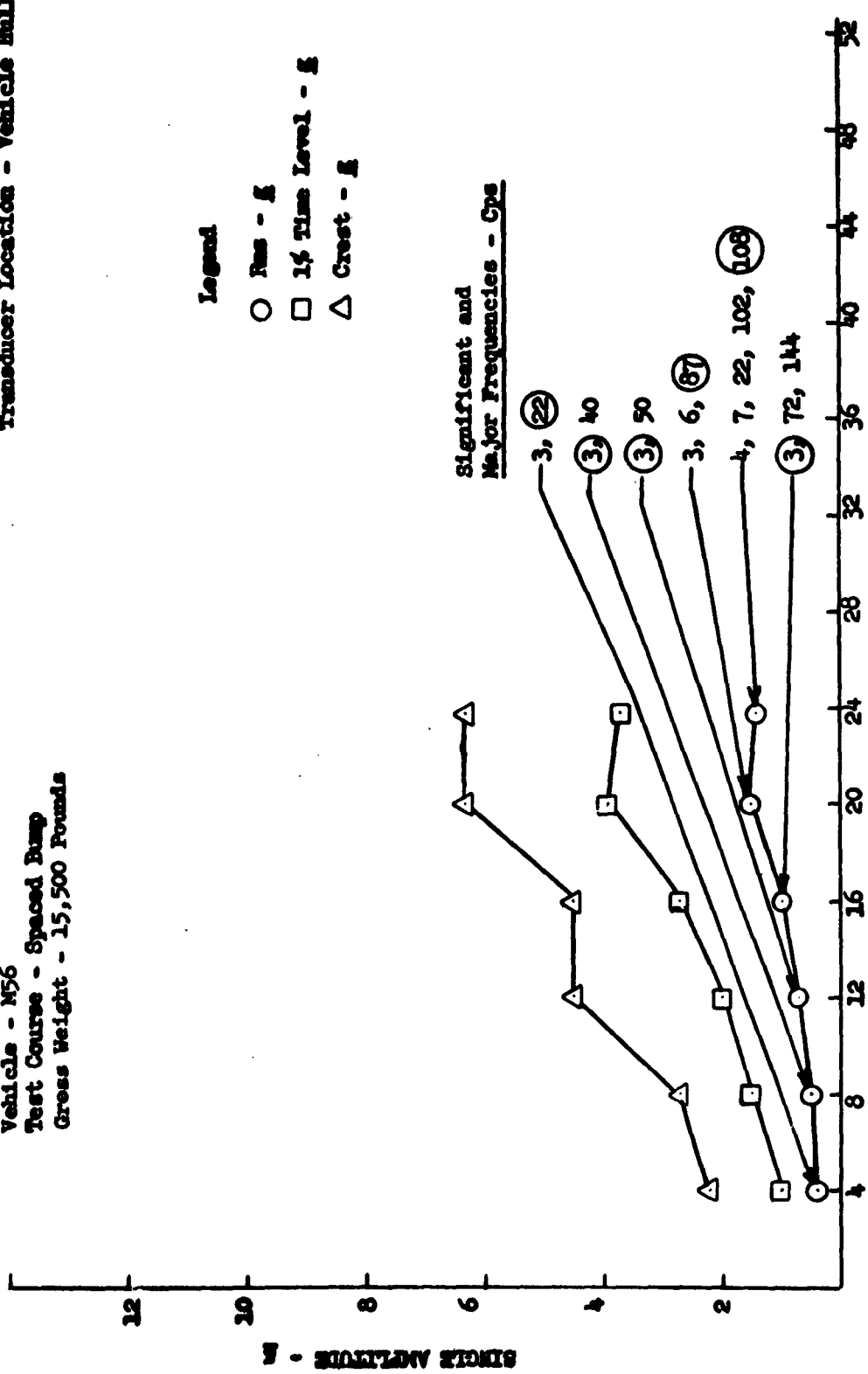
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Transducer Location - Vehicle Roll

Vehicle - M56
Test Course - Spaced Bump
Gross Weight - 15,500 Pounds



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VIBRATION ENVIRONMENT (VERTICAL)

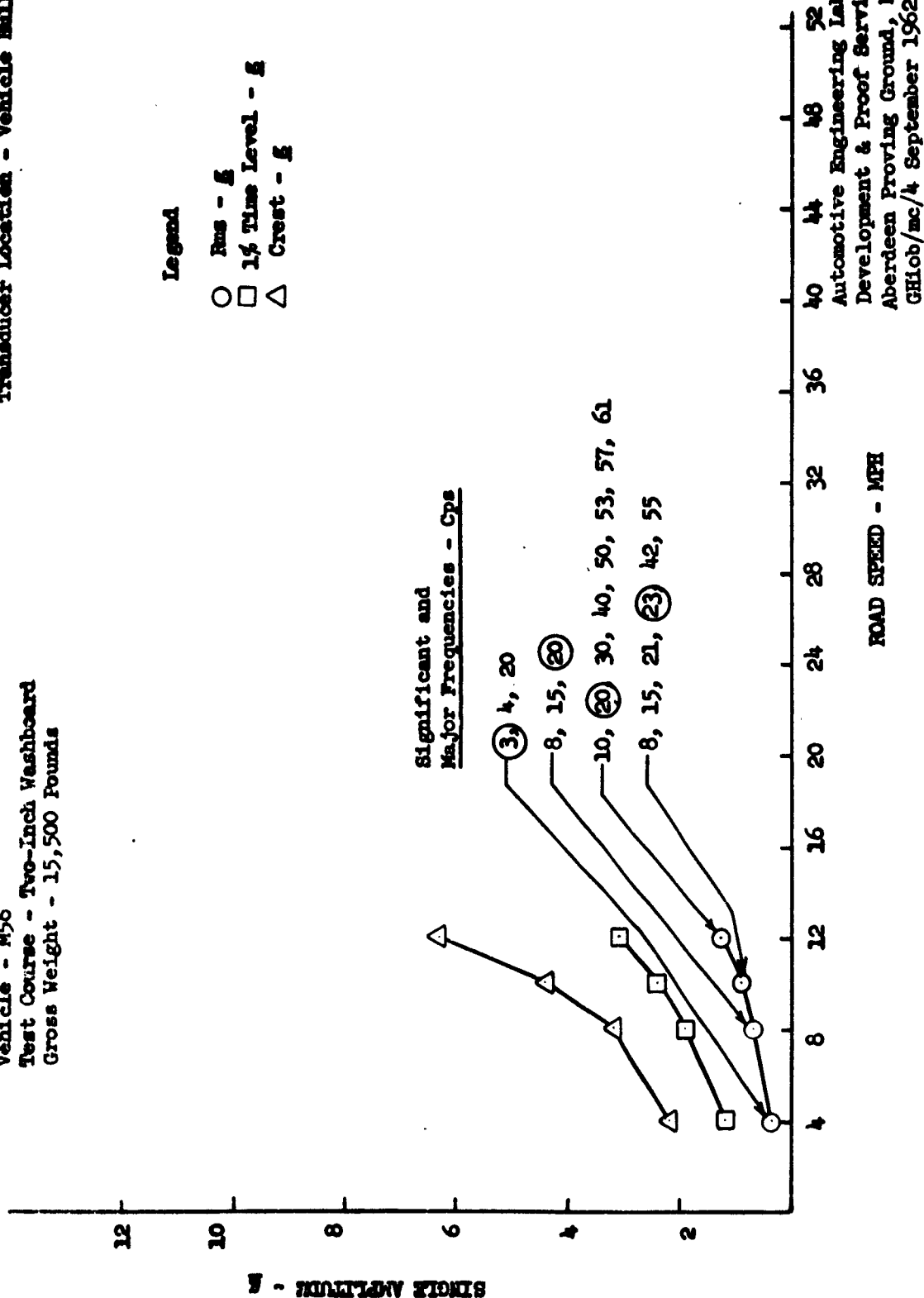
AMPLITUDE VS ROAD SPEED

Vehicle - M56
 Test Course - Two-Inch Washboard
 Gross Weight - 15,500 Pounds

Transducer Location - Vehicle Roll

Legend

- Rms - $\frac{1}{2}$ g
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$ g
- △ Crest - $\frac{1}{2}$ g



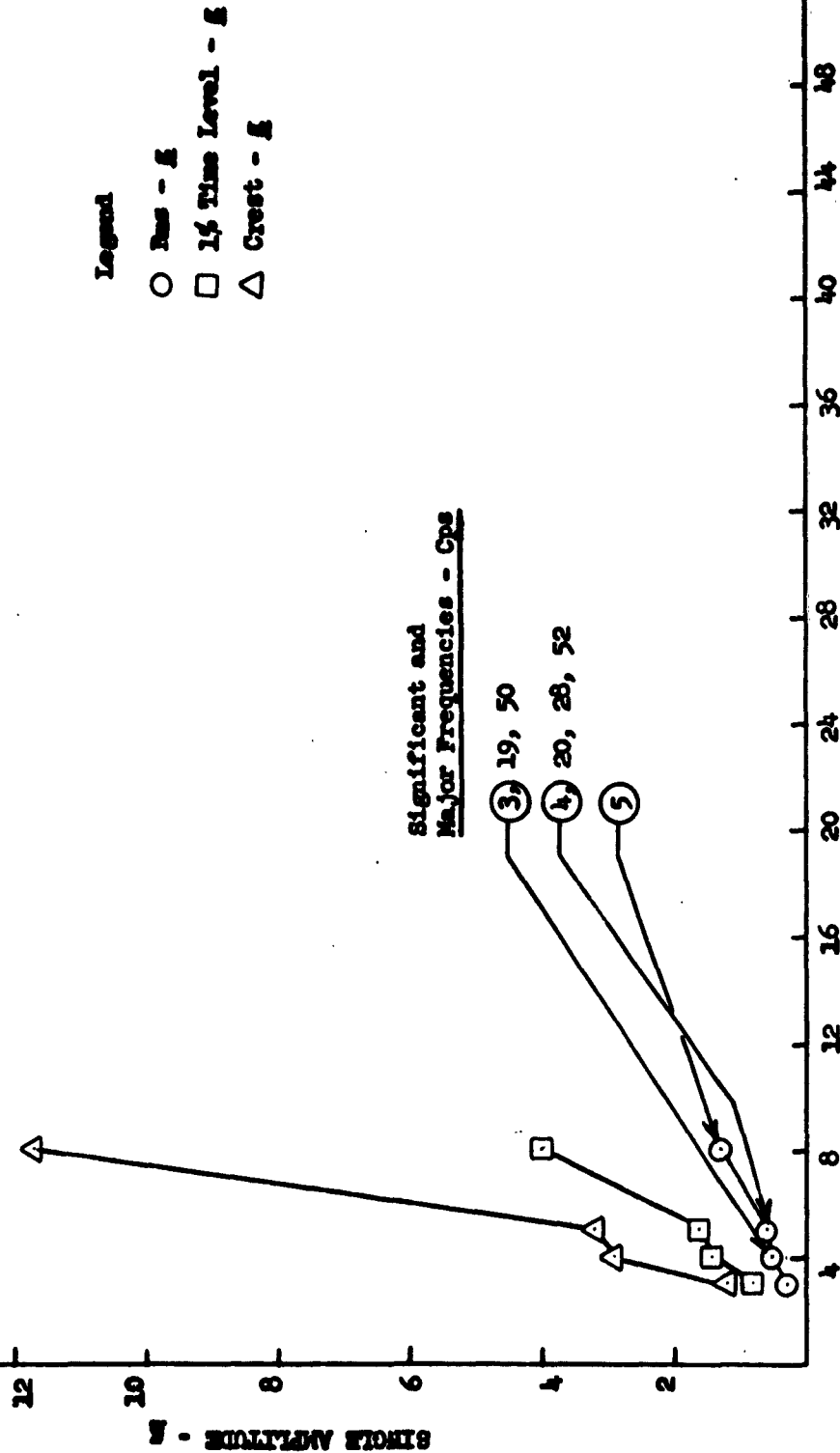
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Transducer Location - Vehicle Hull

Vehicle- M56
Test Course - Six-Inch Washboard
Gross Weight - 15,500 Pounds



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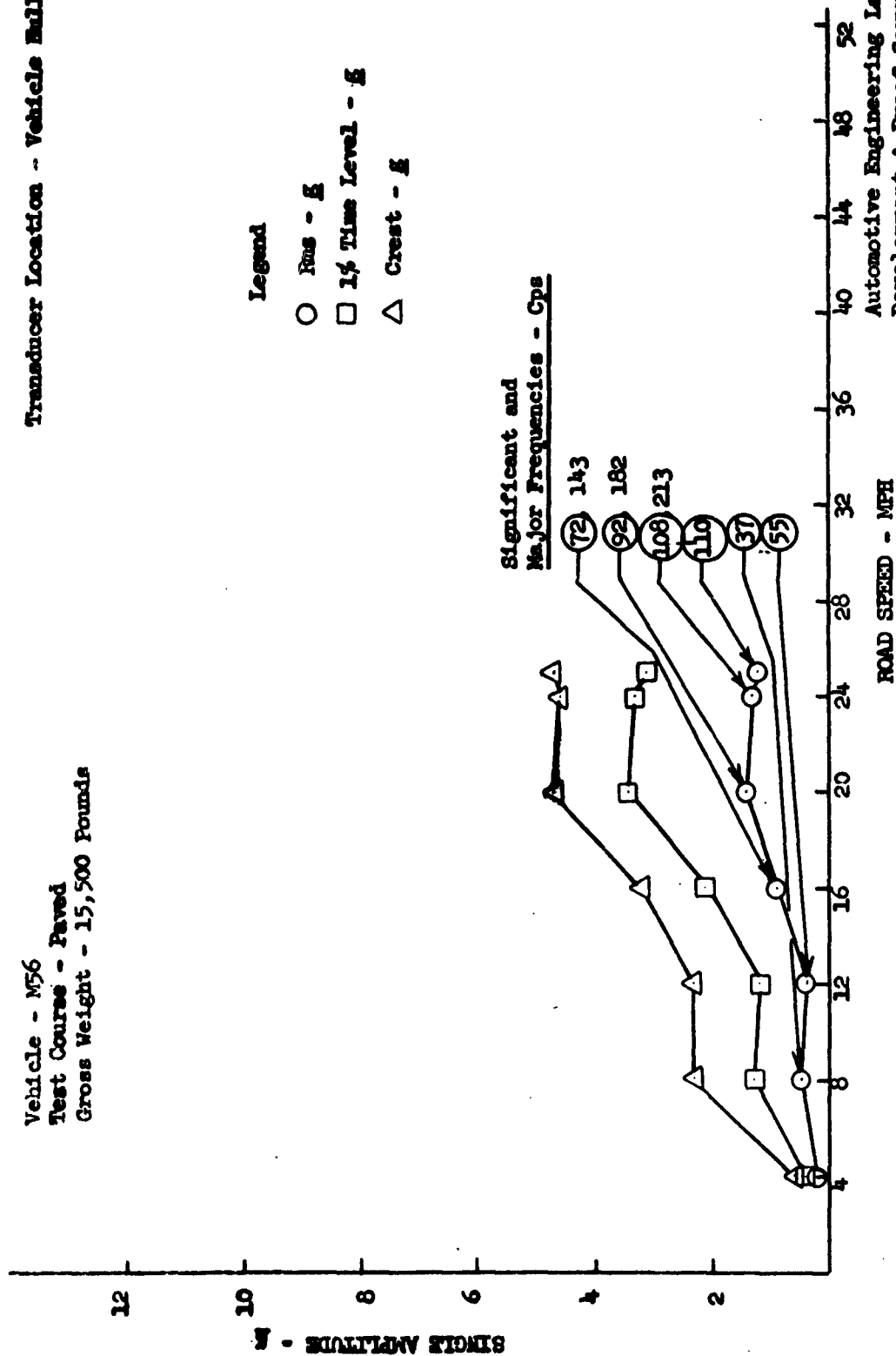
ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M56
 Test Courses - Paved
 Gross Weight - 15,500 Pounds

Transducer Location - Vehicle Hull



Legend

- Rms - g
- 1/3 Time Level - g
- △ Crest - g

Significant and
 Major Frequencies - Cps

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VIBRATION ENVIRONMENT (VERTICAL)

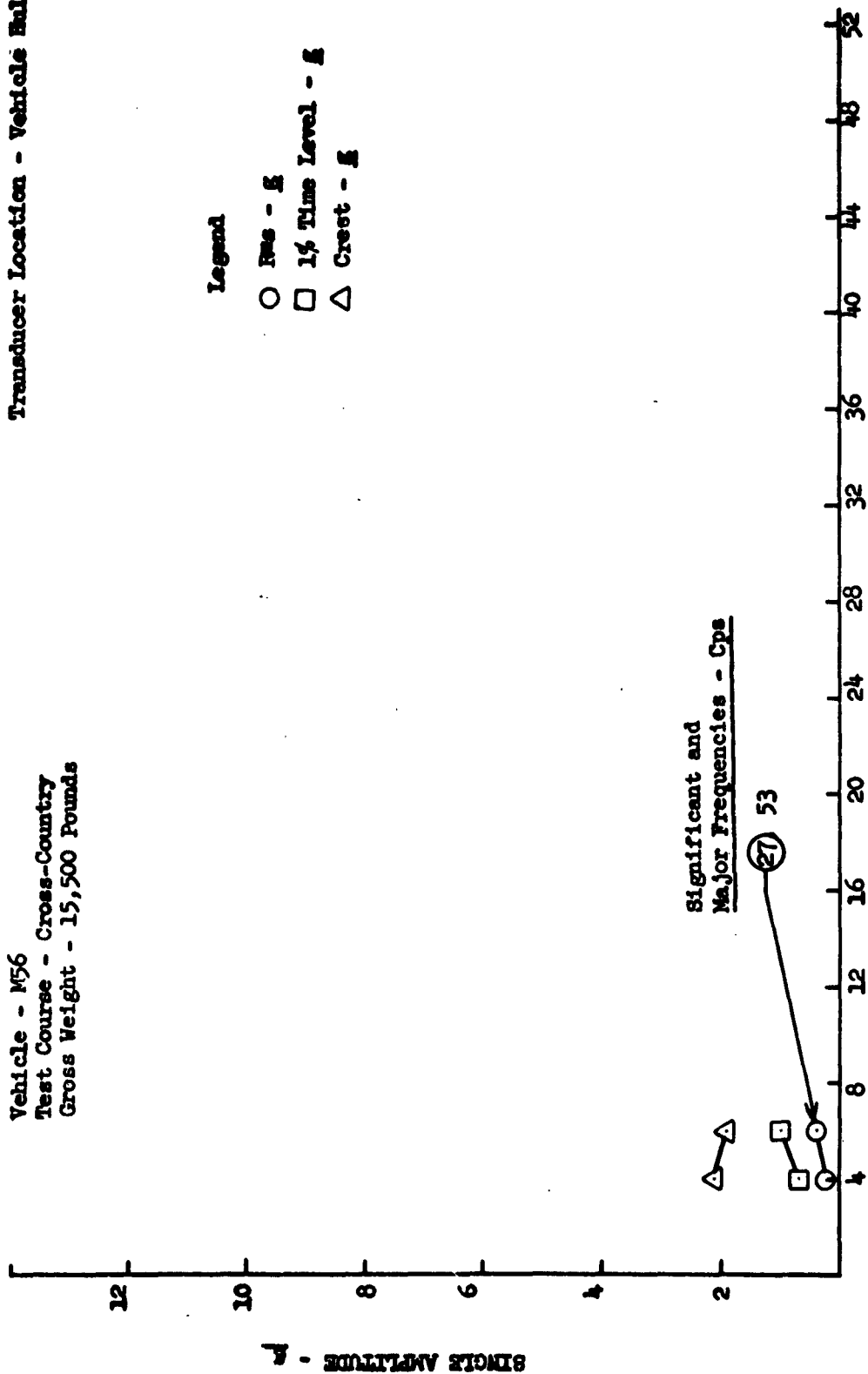
AMPLITUDE VS ROAD SPEED

Vehicle - M56
 Test Course - Cross-Country
 Gross Weight - 15,500 Pounds

Transducer Location - Vehicle Ball

Legend

- Res - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

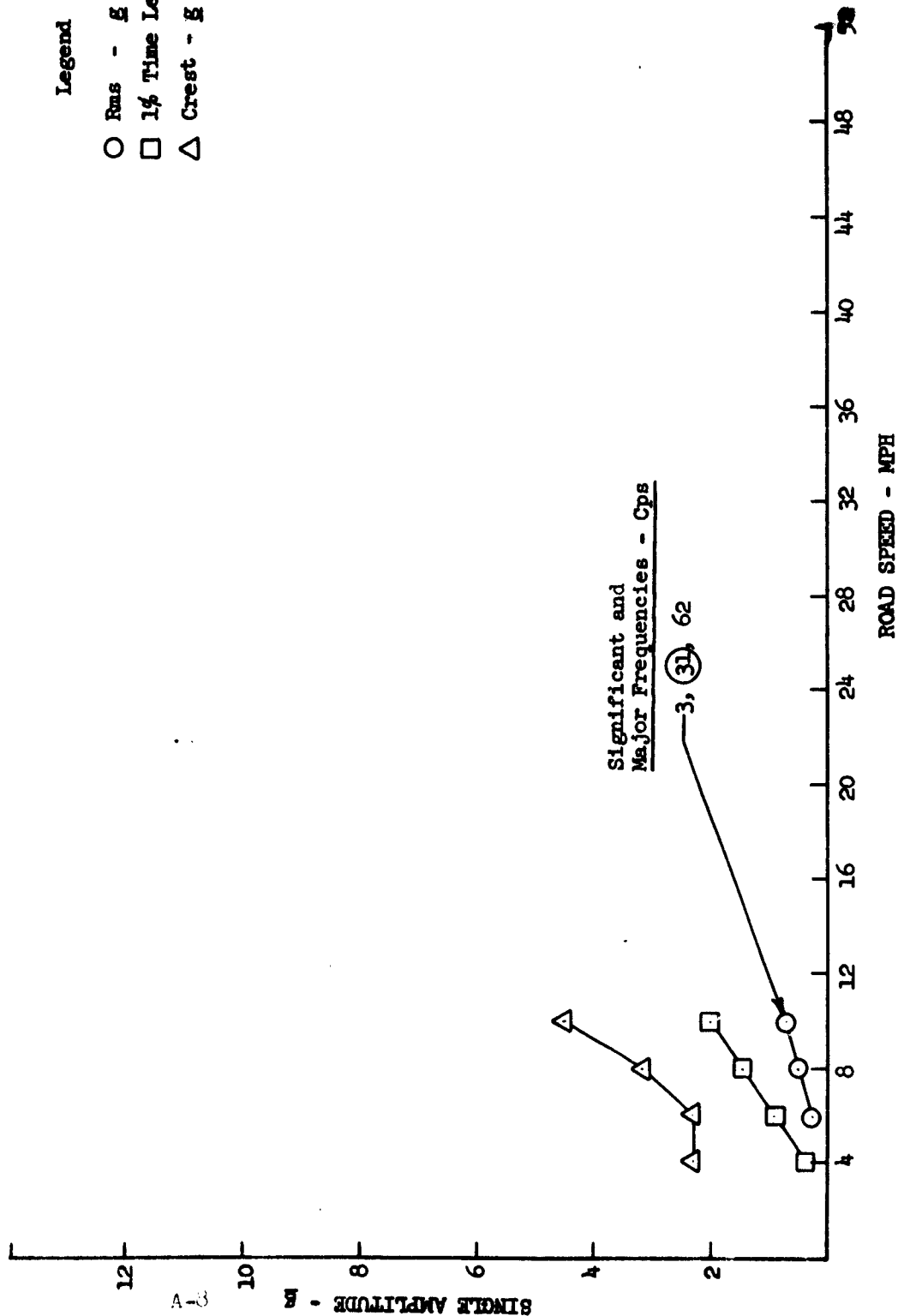
AMPLITUDE VS ROAD SPEED

Vehicle - M41
 Test Course - Cross-Country
 Gross Weight - 51,000 lbs

Transducer Location - Vehicle Hull

Legend

- Rms - \bar{g}
- 1% Time Level - \bar{g}
- △ Crest - \bar{g}



VIBRATION ENVIRONMENT (VERTICAL)

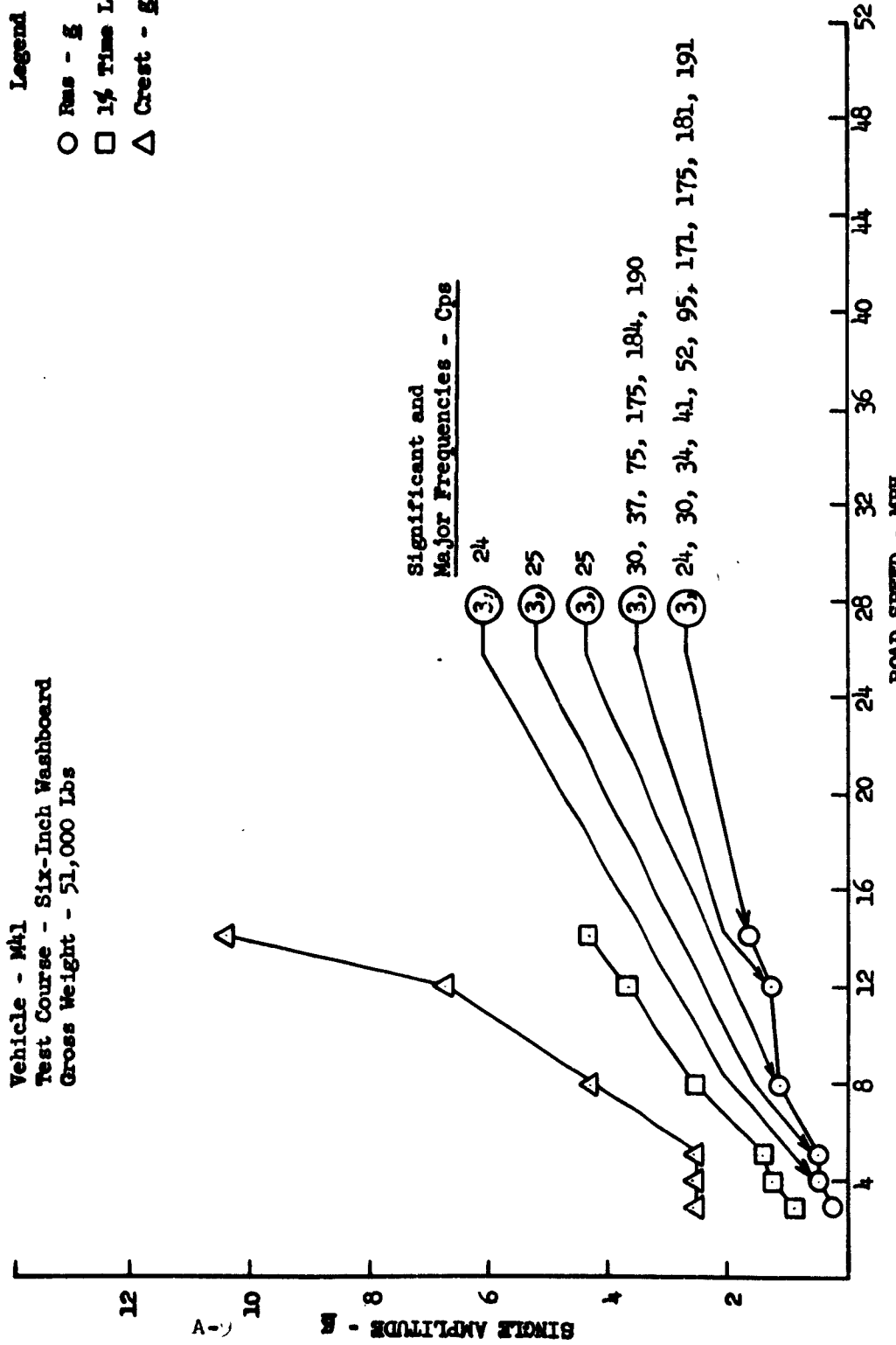
AMPLITUDE VS ROAD SPEED

Transducer Location - Vehicle Hull

Vehicle - M41
Test Course - Six-Inch Washboard
Gross Weight - 51,000 Lbs

Legend

- Run - g
- 1/4 Time Level - g
- △ Crest - g



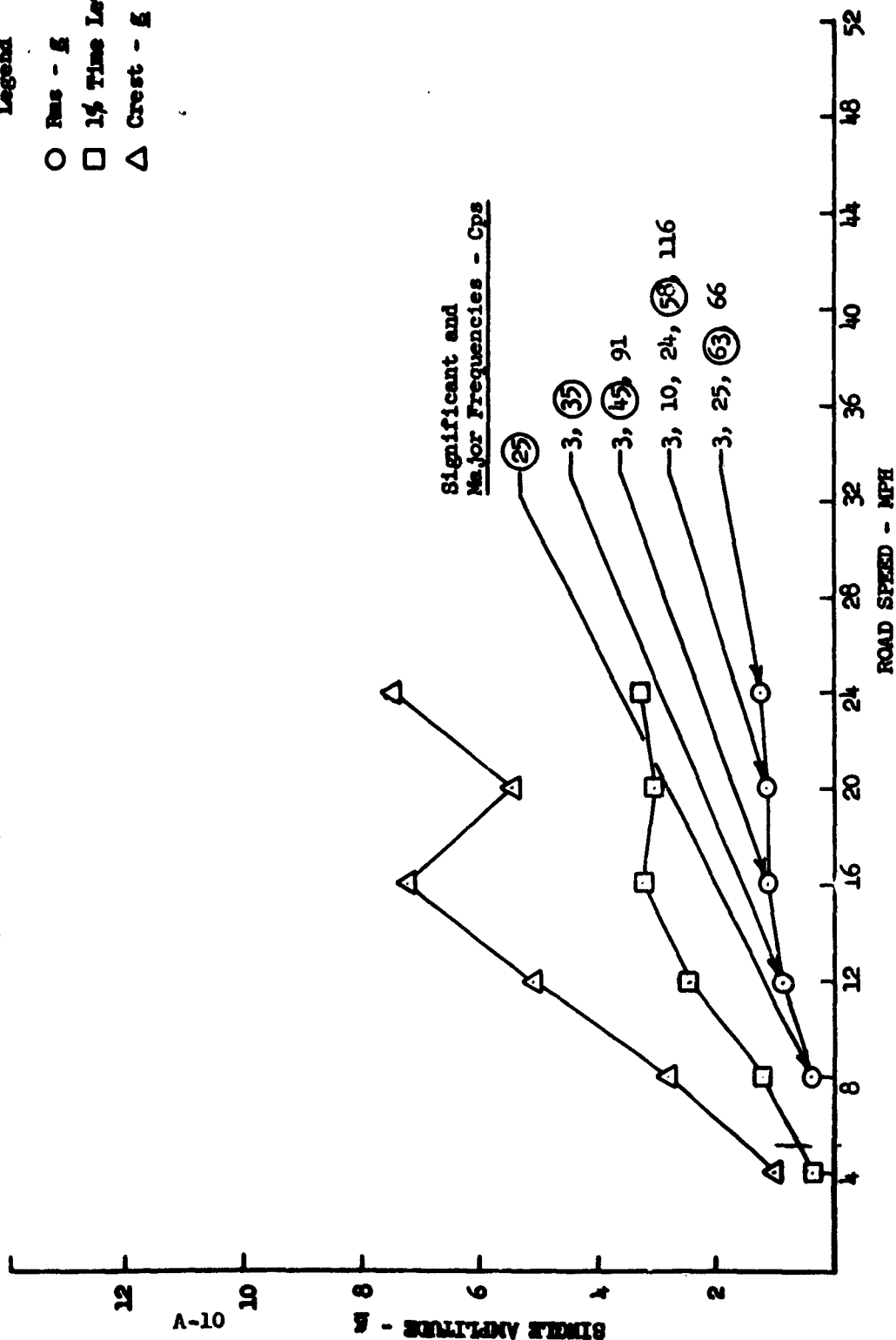
VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Transducer Location - Vehicle Hull

Vehicle - M41
Test Course - Belgian Block
Gross Weight - 51,000 lbs

- Legend
- Run - \bar{x}
 - 1 $\frac{1}{2}$ Time Level - \bar{x}
 - △ Crest - \bar{x}



VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

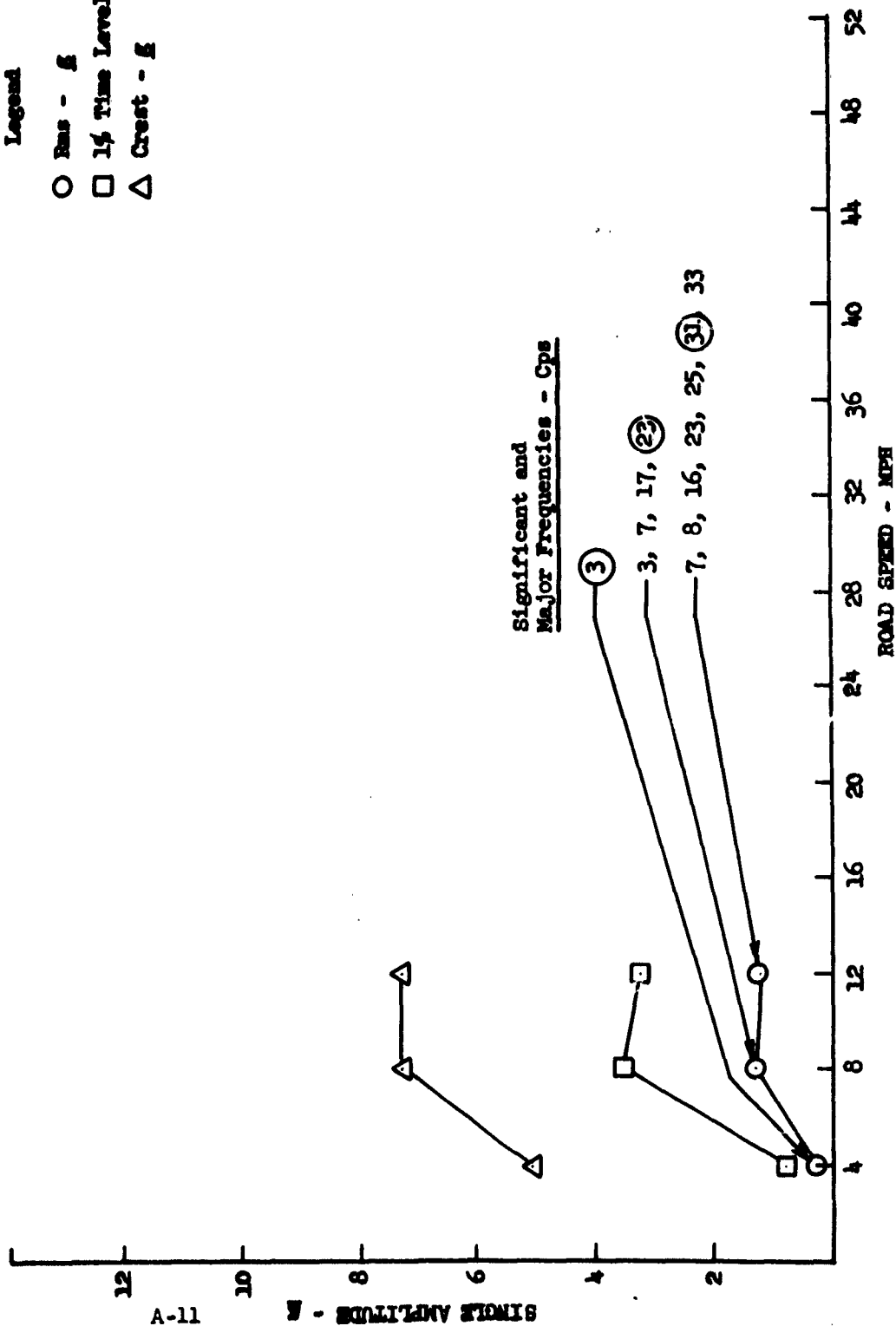
Vehicle - M41

Test Course - Two-Inch Washboard

Gross Weight - 51,000 lbs

Transducer Location - Vehicle Hull

- Legend
- Bus - $\frac{1}{2}$
 - 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
 - △ Crest - $\frac{1}{2}$



A-11

VIBRATION ENVIRONMENT (VERTICAL)

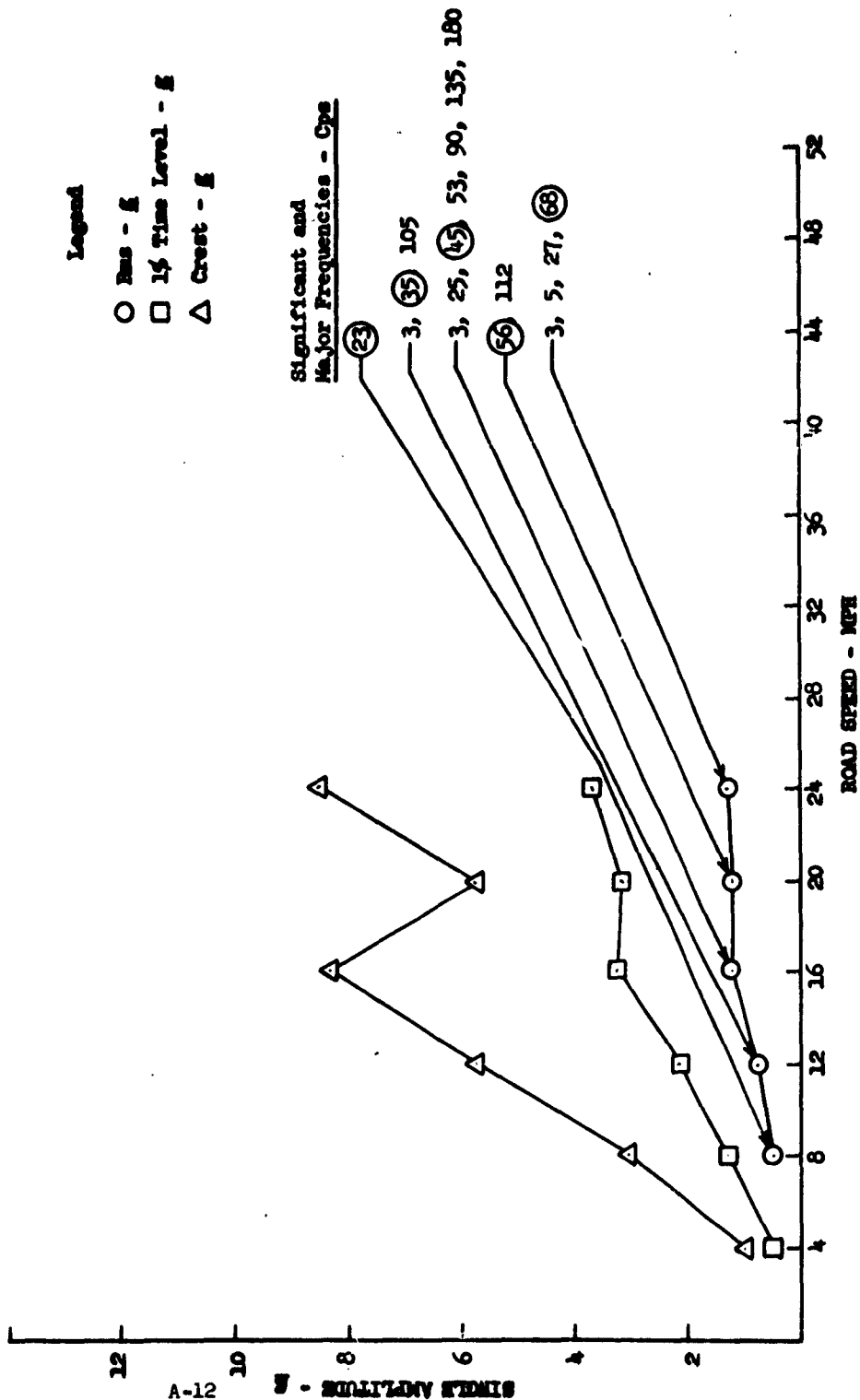
AMPLITUDE VS ROAD SPEED

Vehicle - M41
Test Course - Spaced Bump
Gross Weight - 51,000 lbs

Transducer Location - Vehicle Roll

Legend

- Bus - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



VIBRATION ENVIRONMENT (VERTICAL)

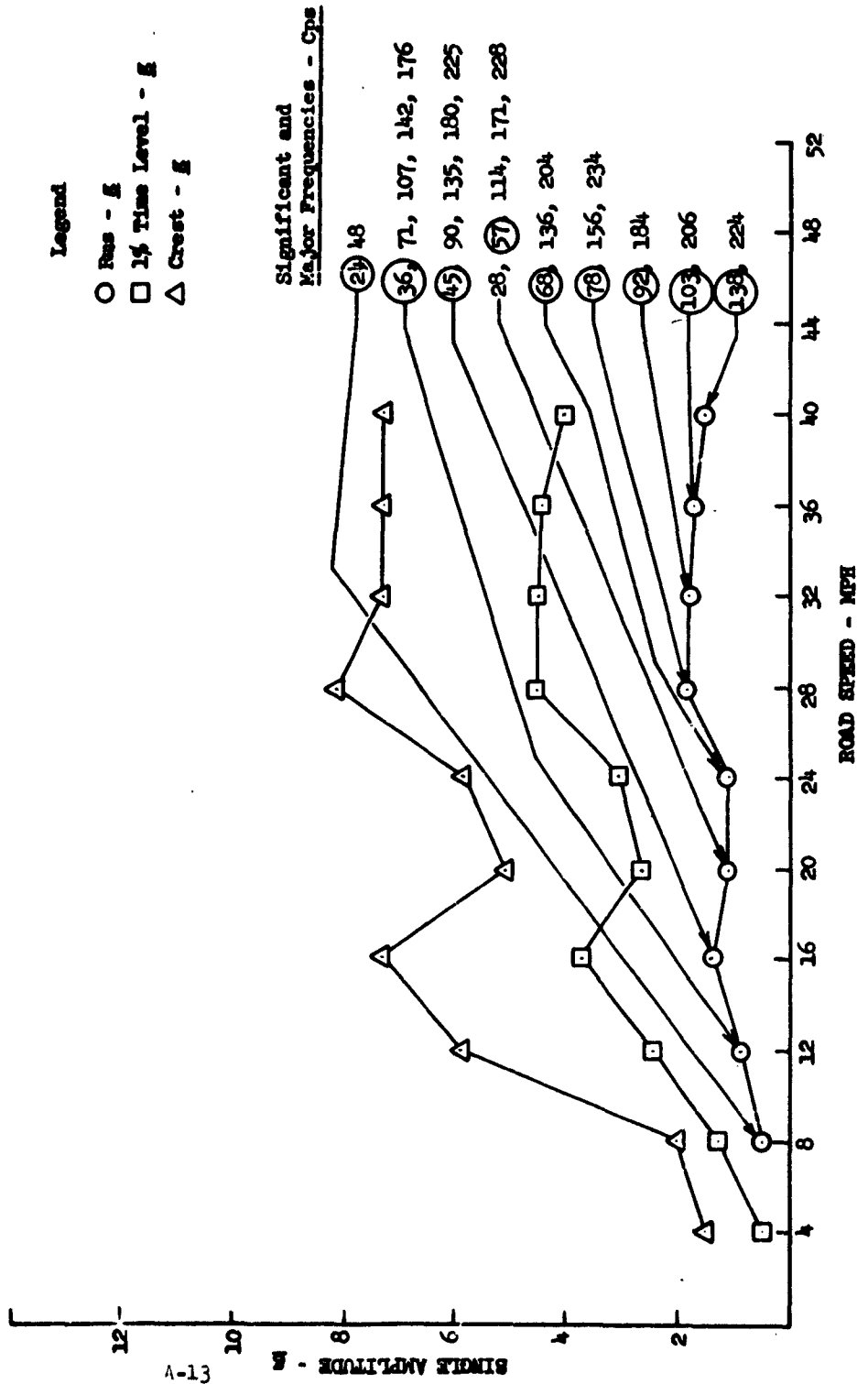
AMPLITUDE VS ROAD SPEED

Vehicle - M41
 Test Course - Paved
 Gross Weight - 51,000 lbs

Transducer Location - Vehicle Hull

Legend

- Run - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$

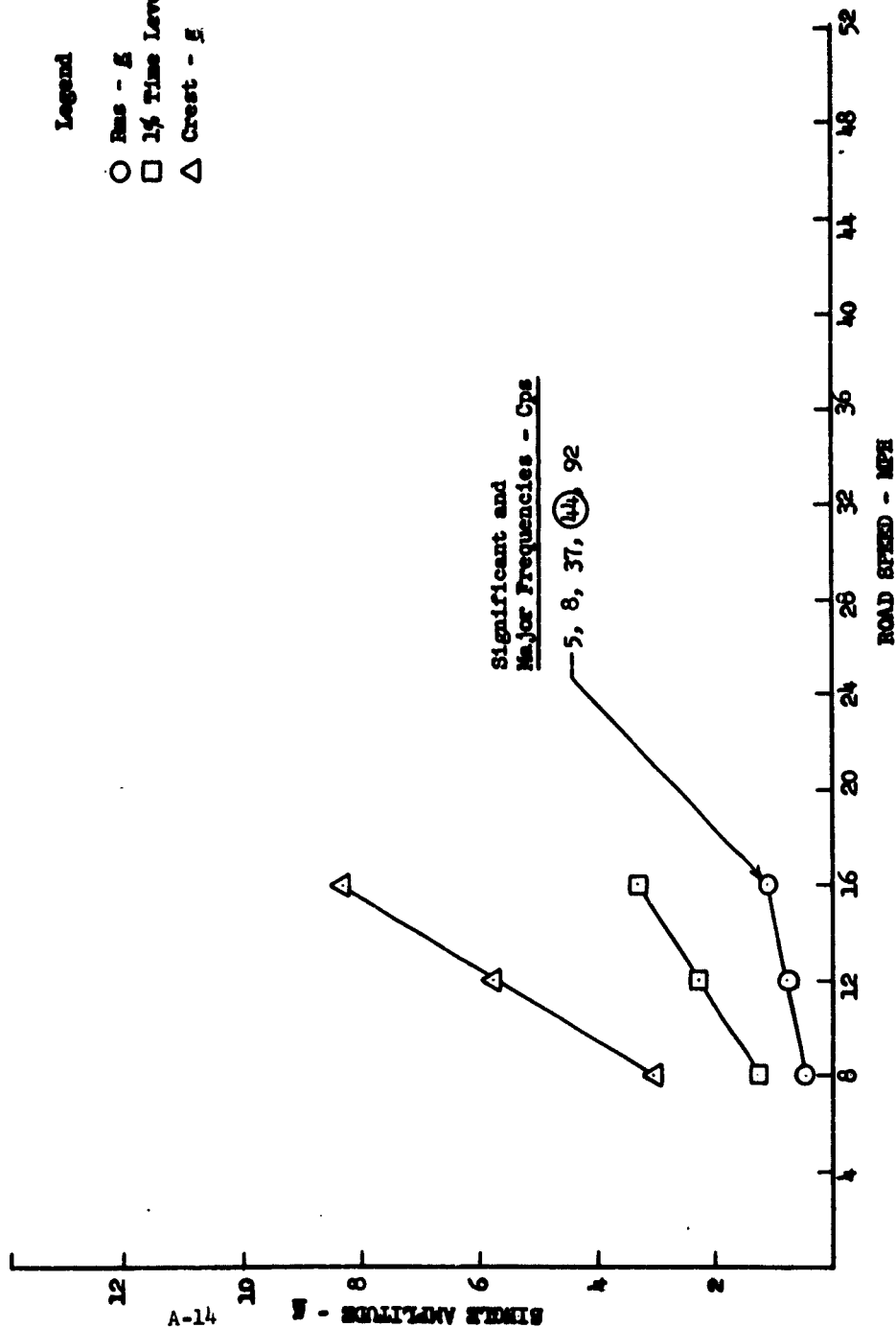


VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M41
 Test Course - Radial Washboard
 Gross Weight - 51,000 lbs

Transducer Location - Vehicle Hull



VIBRATION ENVIRONMENT (VERTICAL)

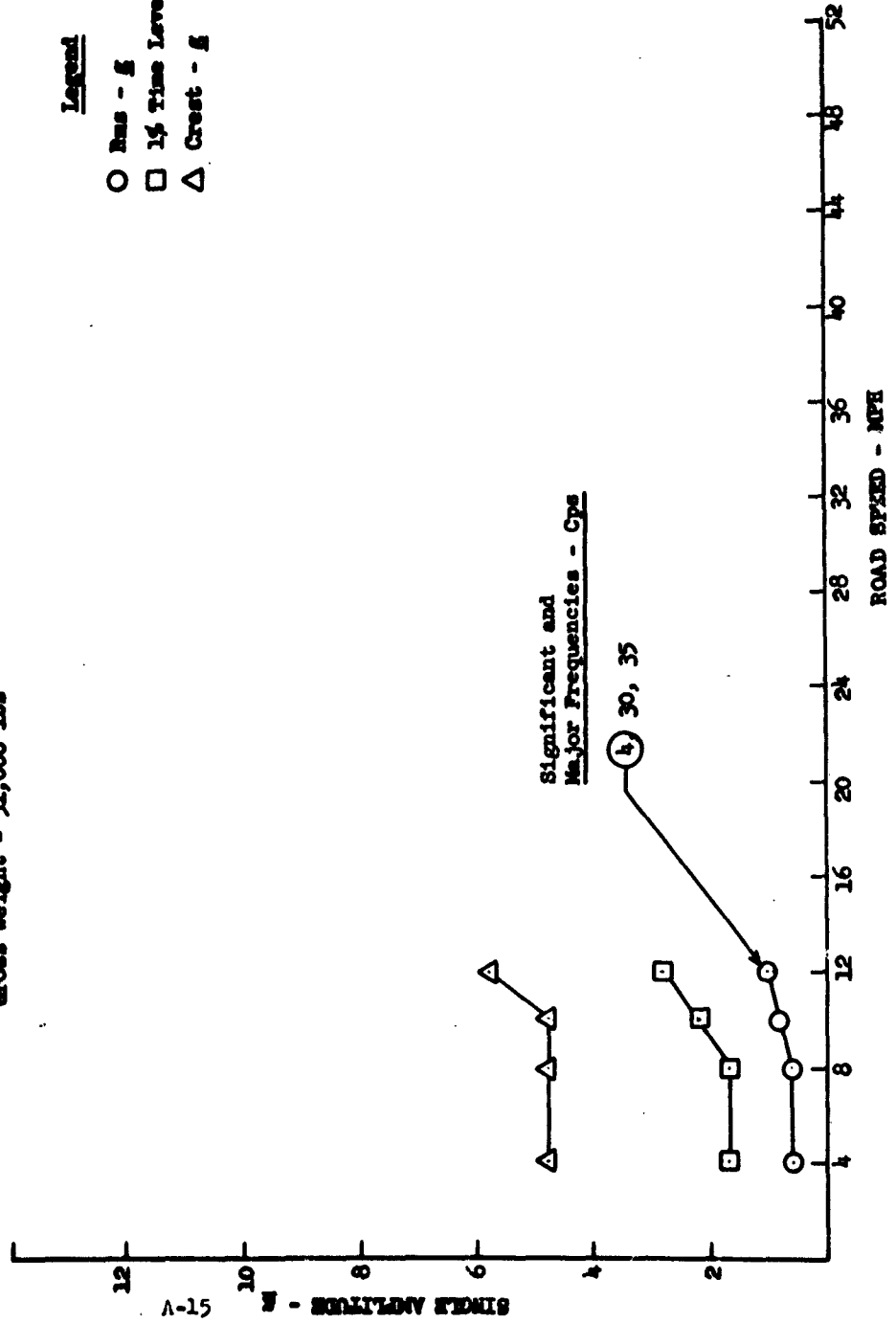
AMPLITUDE VS ROAD SPEED

Vehicle - M41
Test Course - Six-Inch Bump
Gross Weight - 51,000 lbs

Transducer Location - Vehicle Ball

Legend

- Bus - g
- 1 1/2 Time Level - g
- △ Crest - g



A-15

VIBRATION ENVIRONMENT (VERTICAL)

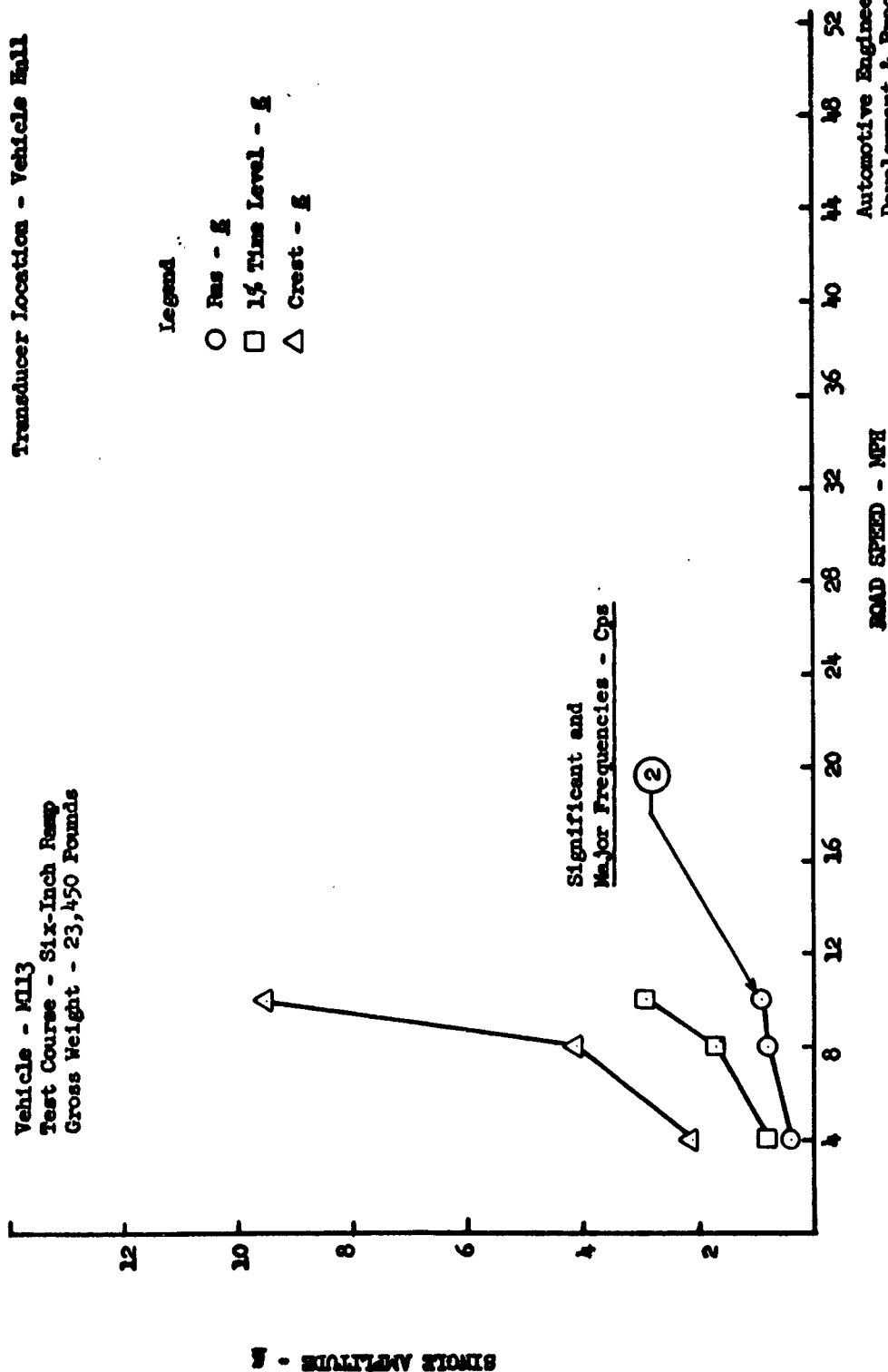
AMPLITUDE VS ROAD SPEED

Transducer Location - Vehicle Roll

Vehicle - M113
Test Course - Six-Inch Ramp
Gross Weight - 23,450 Pounds

Legend

- Roll - $\frac{1}{2}$
- 1/2 Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



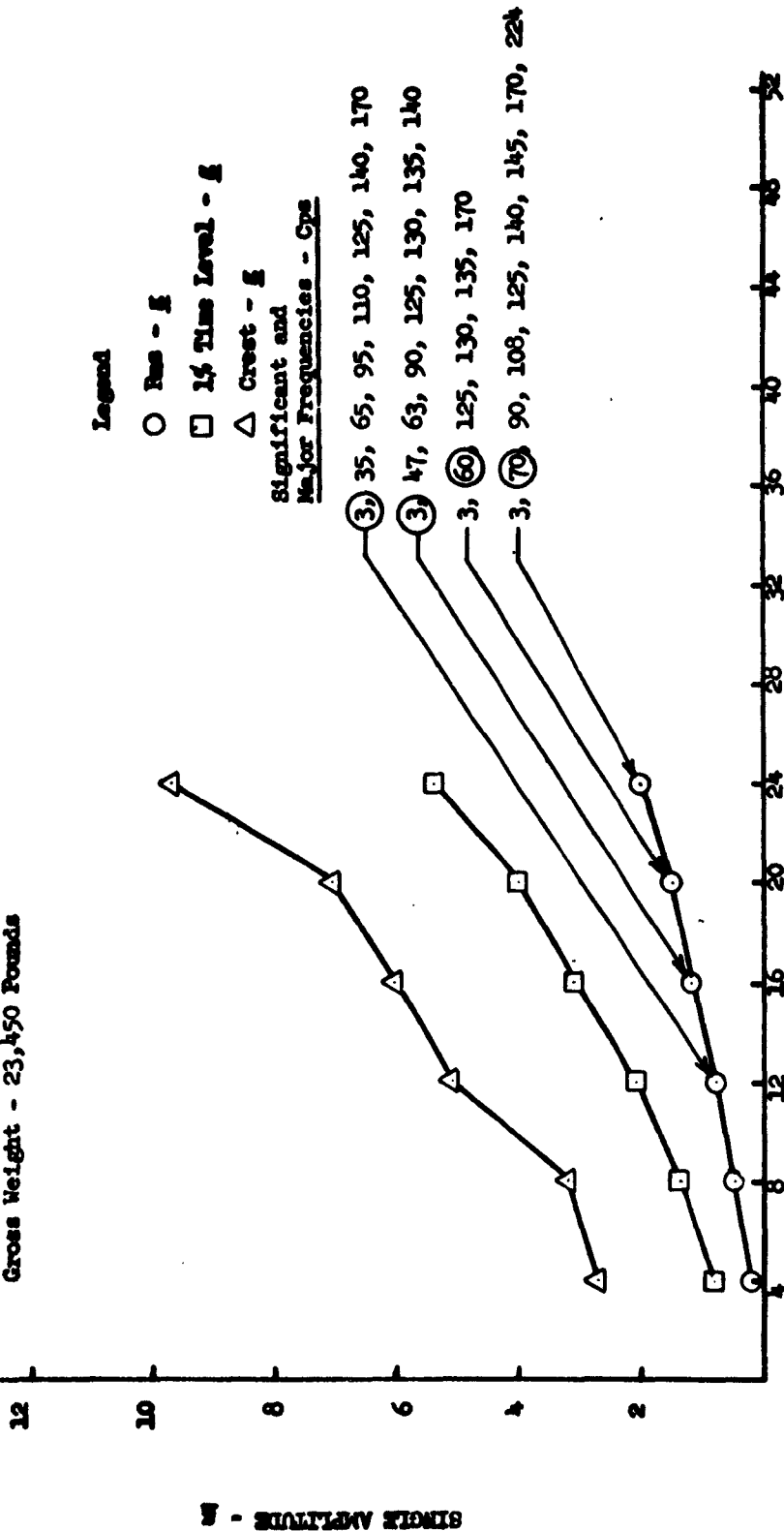
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M113
Test Course - Belgian Block
Gross Weight - 23,450 Pounds

Transducer Location - Vehicle Hull



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VIBRATION ENVIRONMENT (VERTICAL)

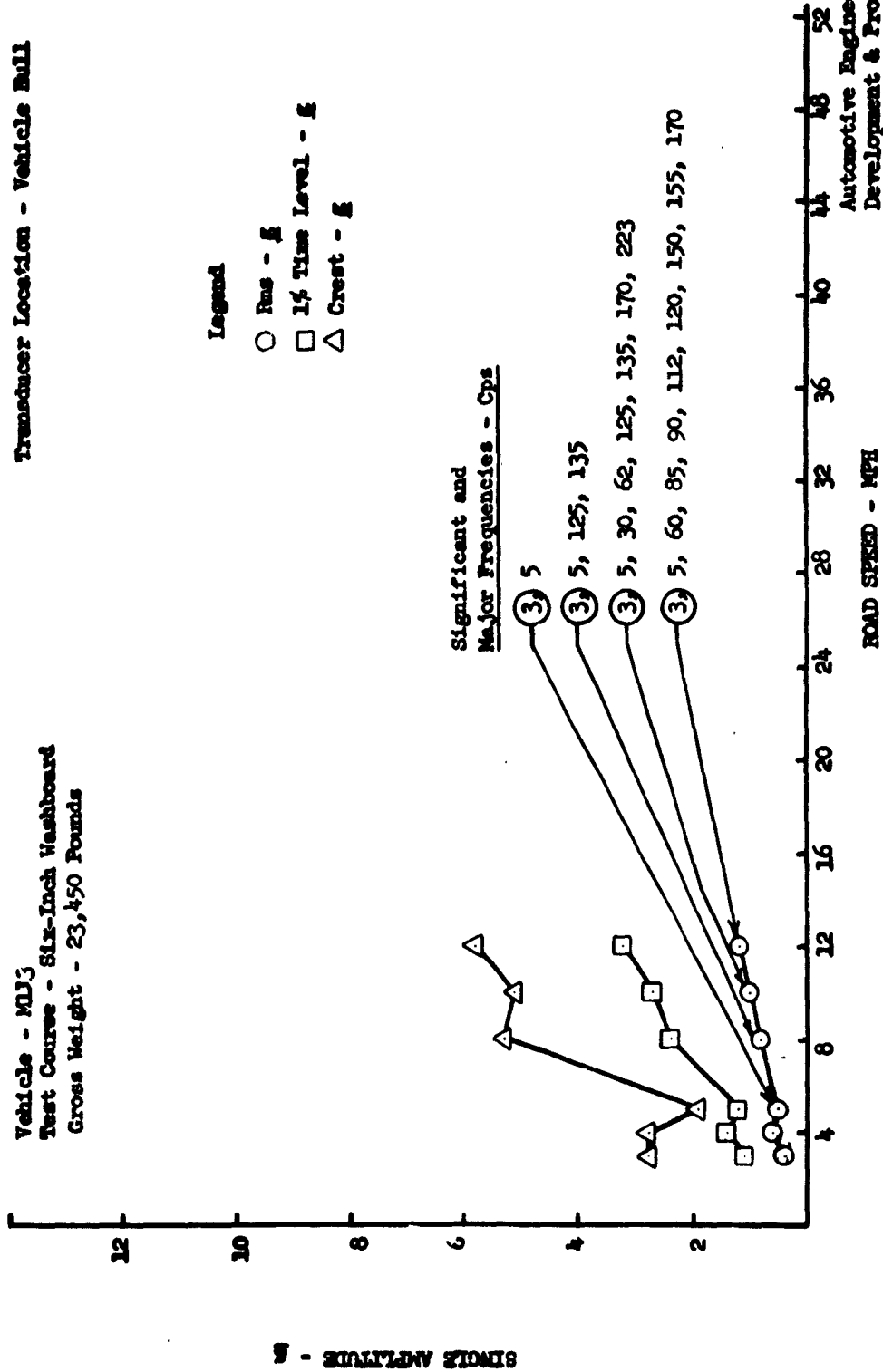
AMPLITUDE VS ROAD SPEED

Vehicle - MJ3
 Test Course - Six-Inch Washboard
 Gross Weight - 23,450 Pounds

Transducer Location - Vehicle Hull

Legend

- Rms - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

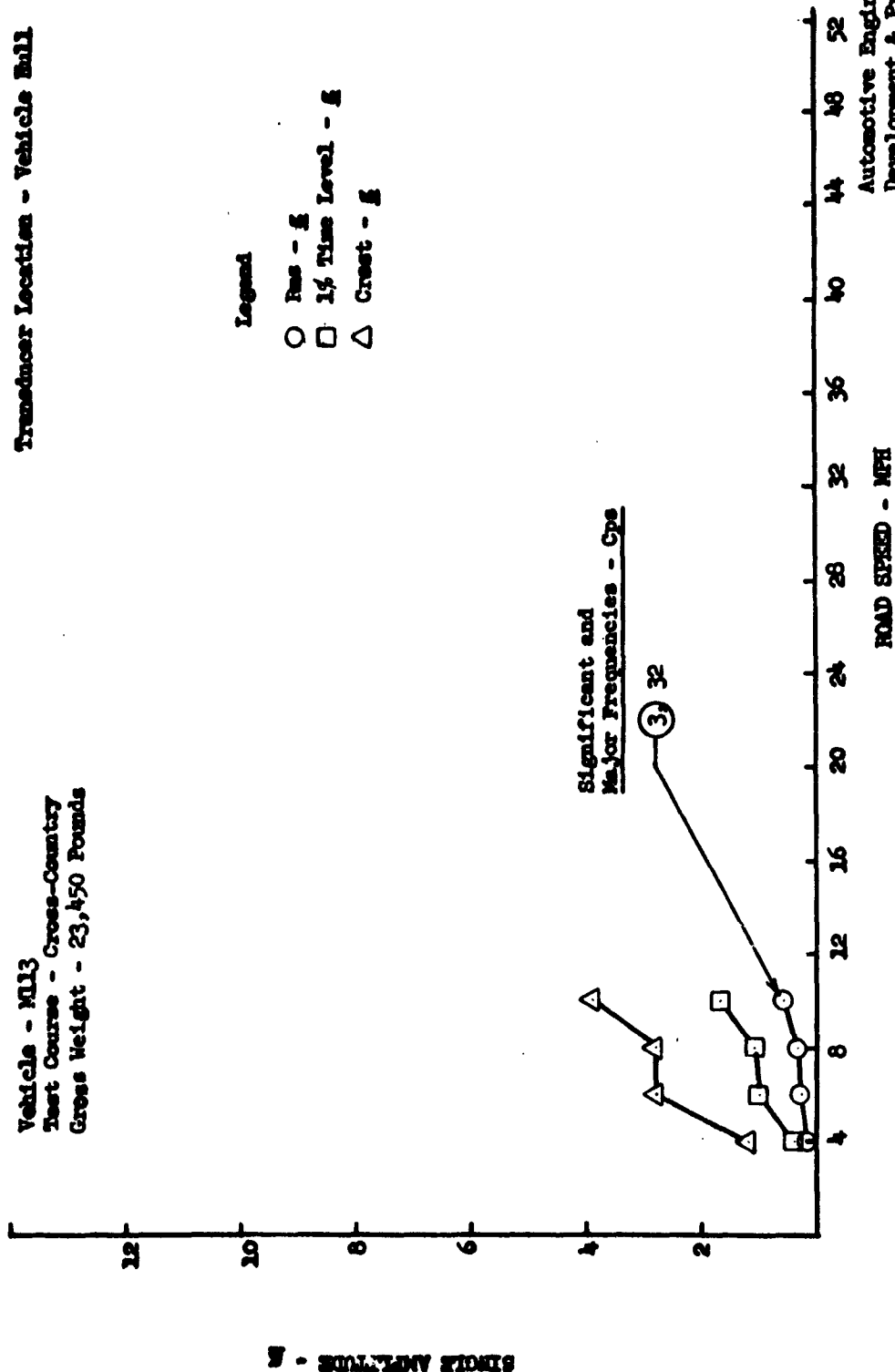
Vehicle - M113

Test Course - Cross-Country

Gross Weight - 23,450 Pounds

Legend

- Res - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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SINGLE AMPLITUDE - g

VIBRATION ENVIRONMENT (VERTICAL)

ACCELERATION VS ROAD SPEED

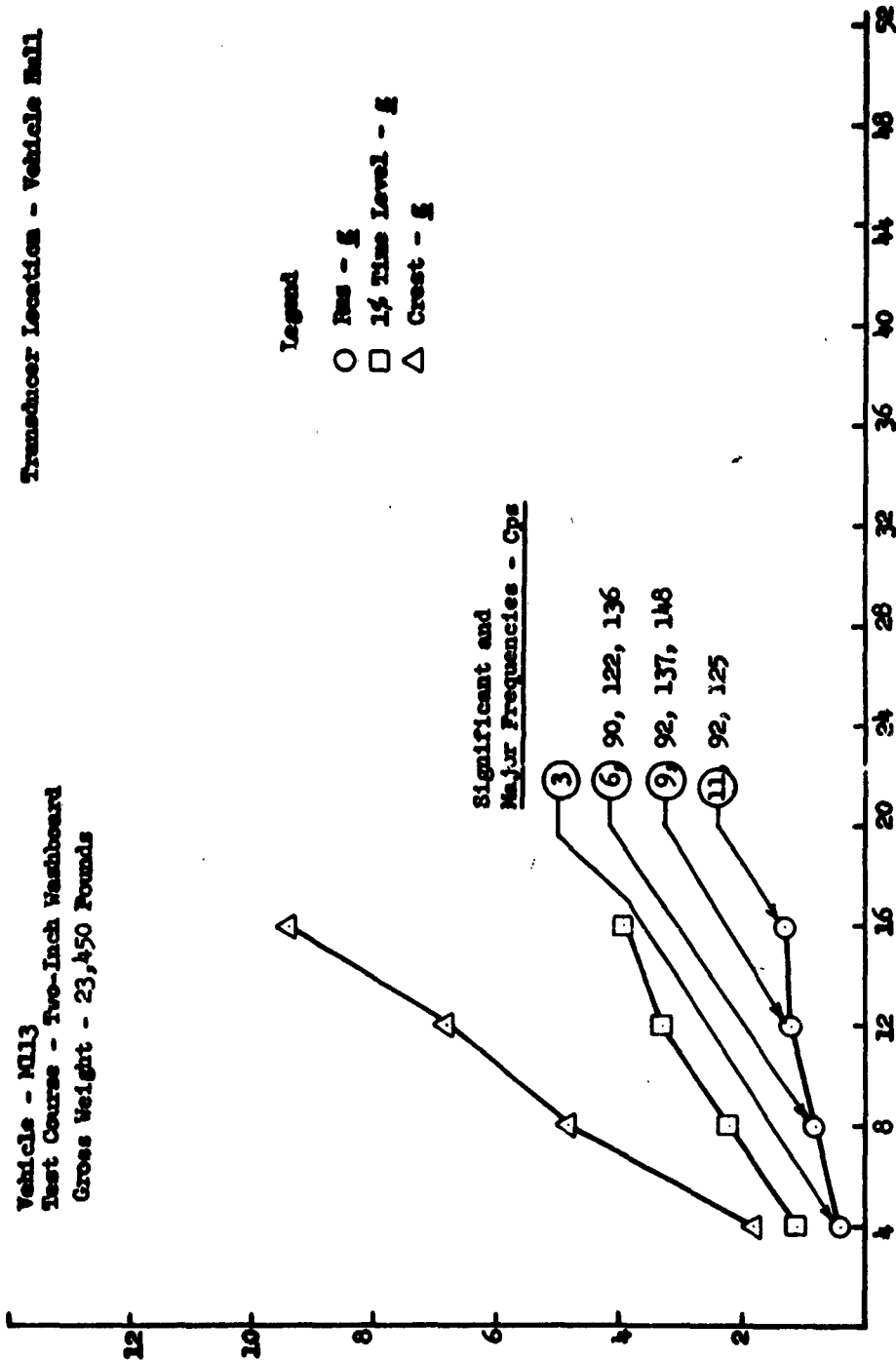
Vehicle - M113
Test Course - Two-Inch Washboard
Gross Weight - 23,450 Pounds

Transducer Location - Vehicle Hull

SINGLE AMPLITUDE - g

Legend
○ Run - g
□ 1/3 Time Level - g
△ Crest - g

Significant and
Major Frequencies - Cps



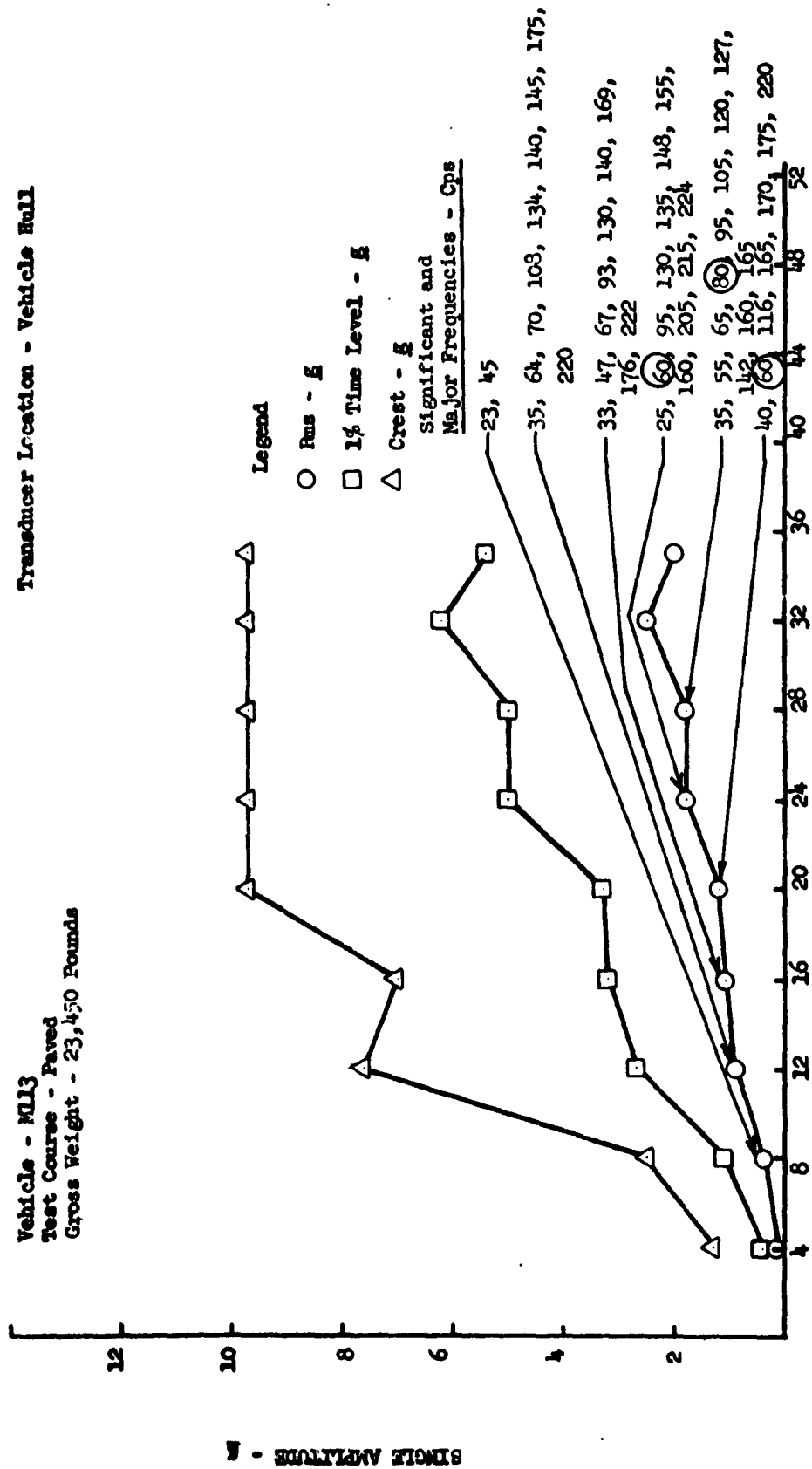
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M113
Test Course - Paved
Gross Weight - 23,450 Pounds

Transducer Location - Vehicle Hull



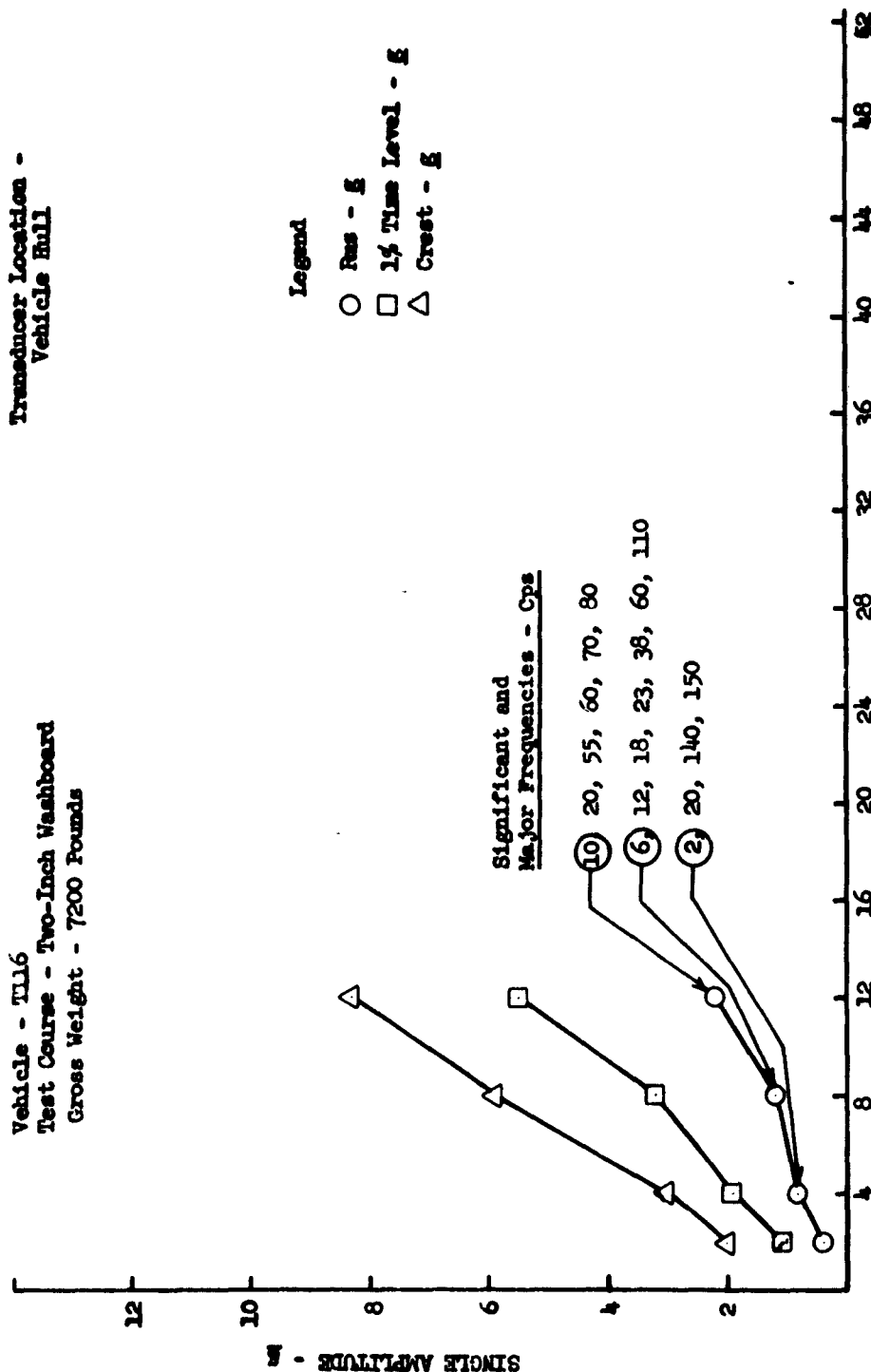
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
 Test Course - Two-Inch Washboard
 Gross Weight - 7200 Pounds

Transducer Location -
 Vehicle Hull



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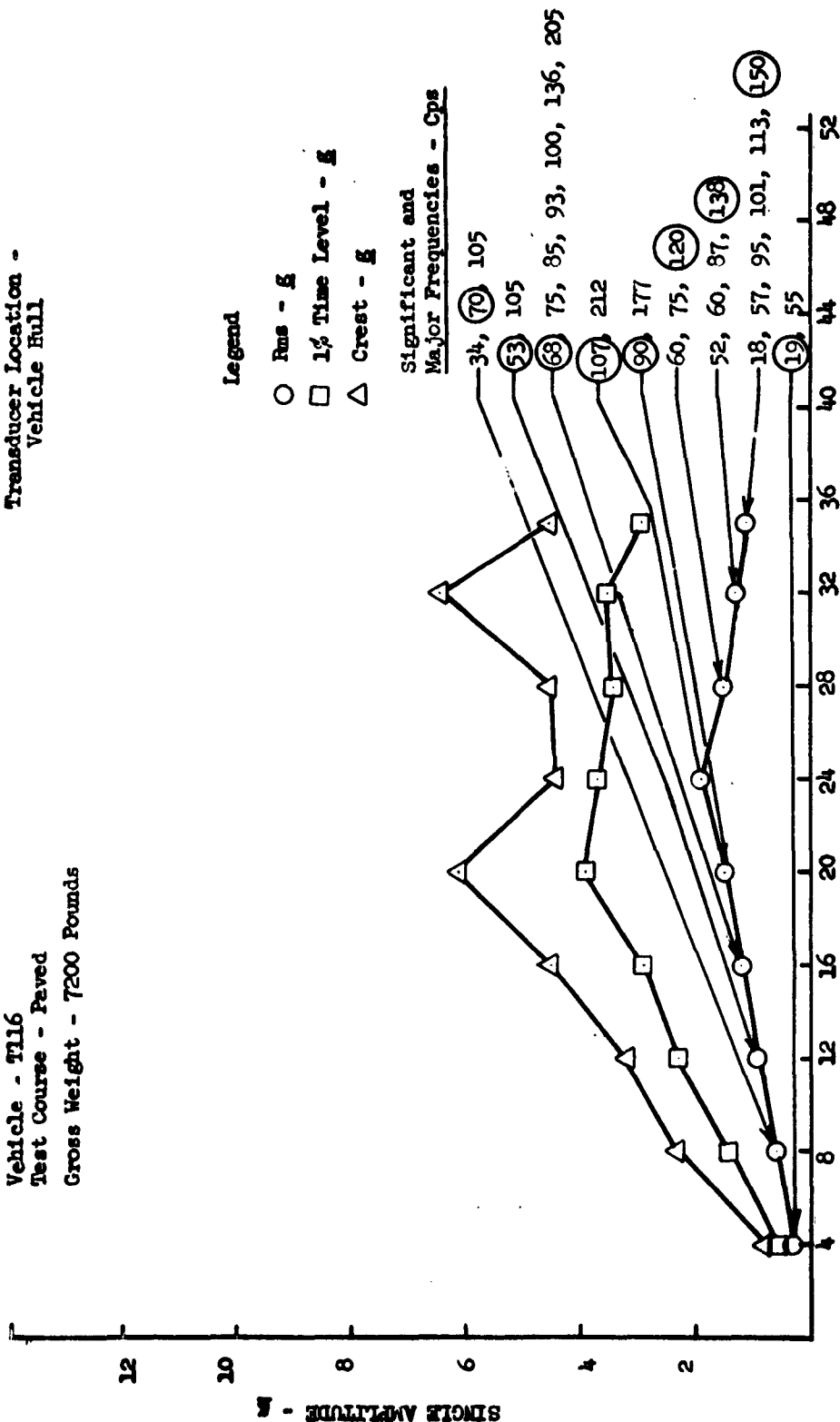
ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
Test Course - Paved
Gross Weight - 7200 Pounds

Transducer Location -
Vehicle Hull



ROAD SPEED - MPH

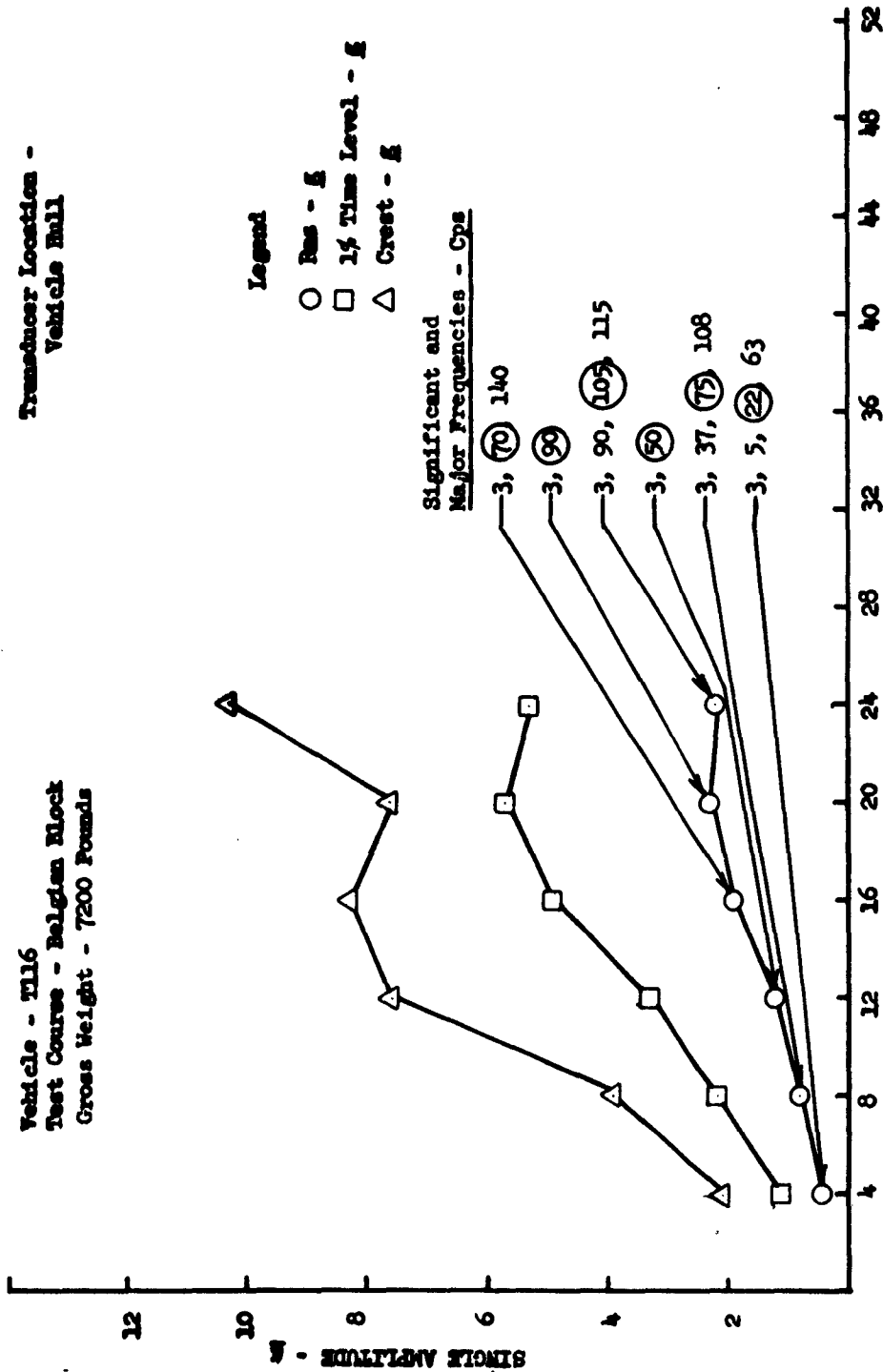
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
Test Course - Belgian Block
Gross Weight - 7200 Pounds

Transducer Location -
Vehicle Hull



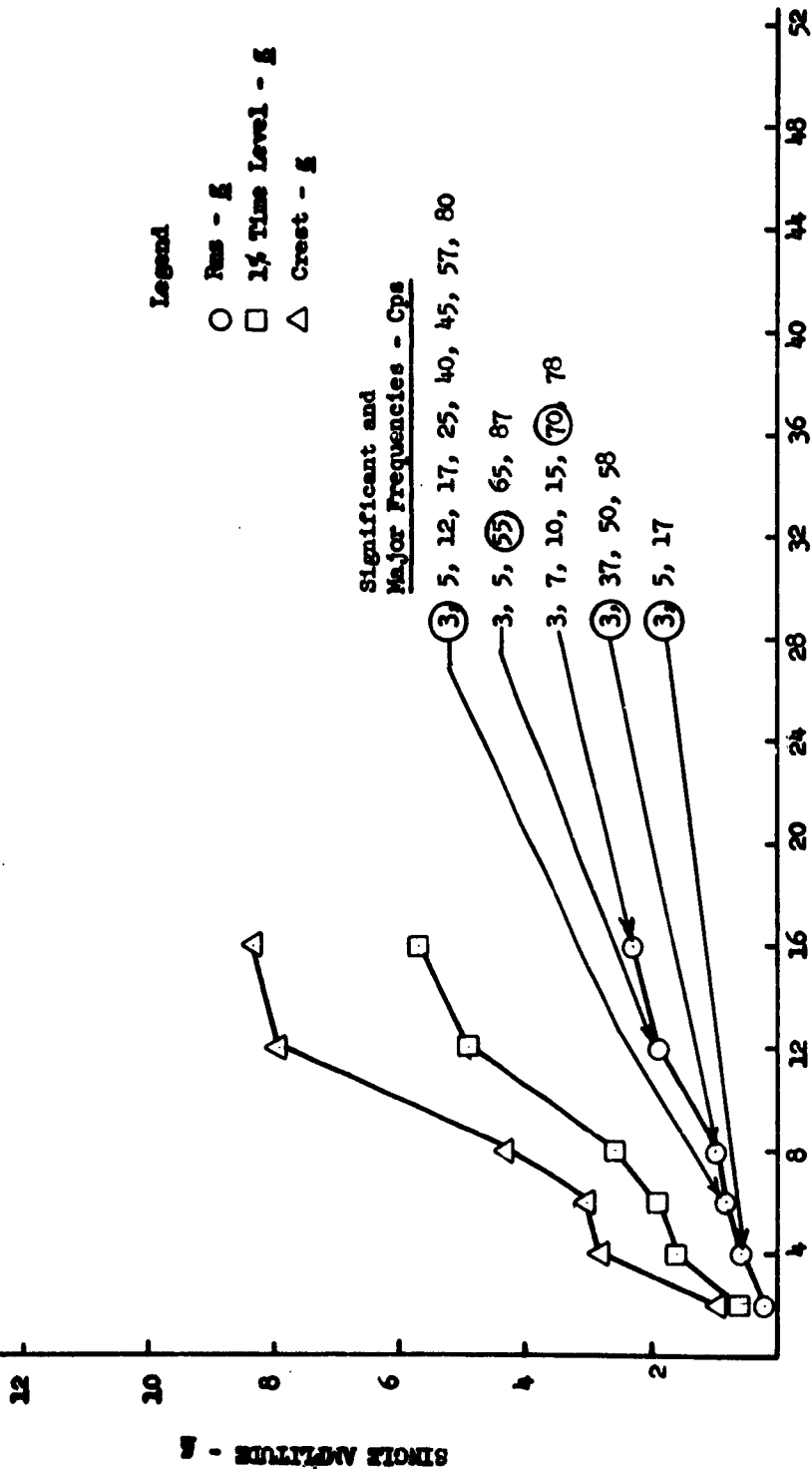
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
 Test Course - Six-Inch Washboard
 Gross Weight - 7200 Pounds

Transducer Location -
 Vehicle Hull



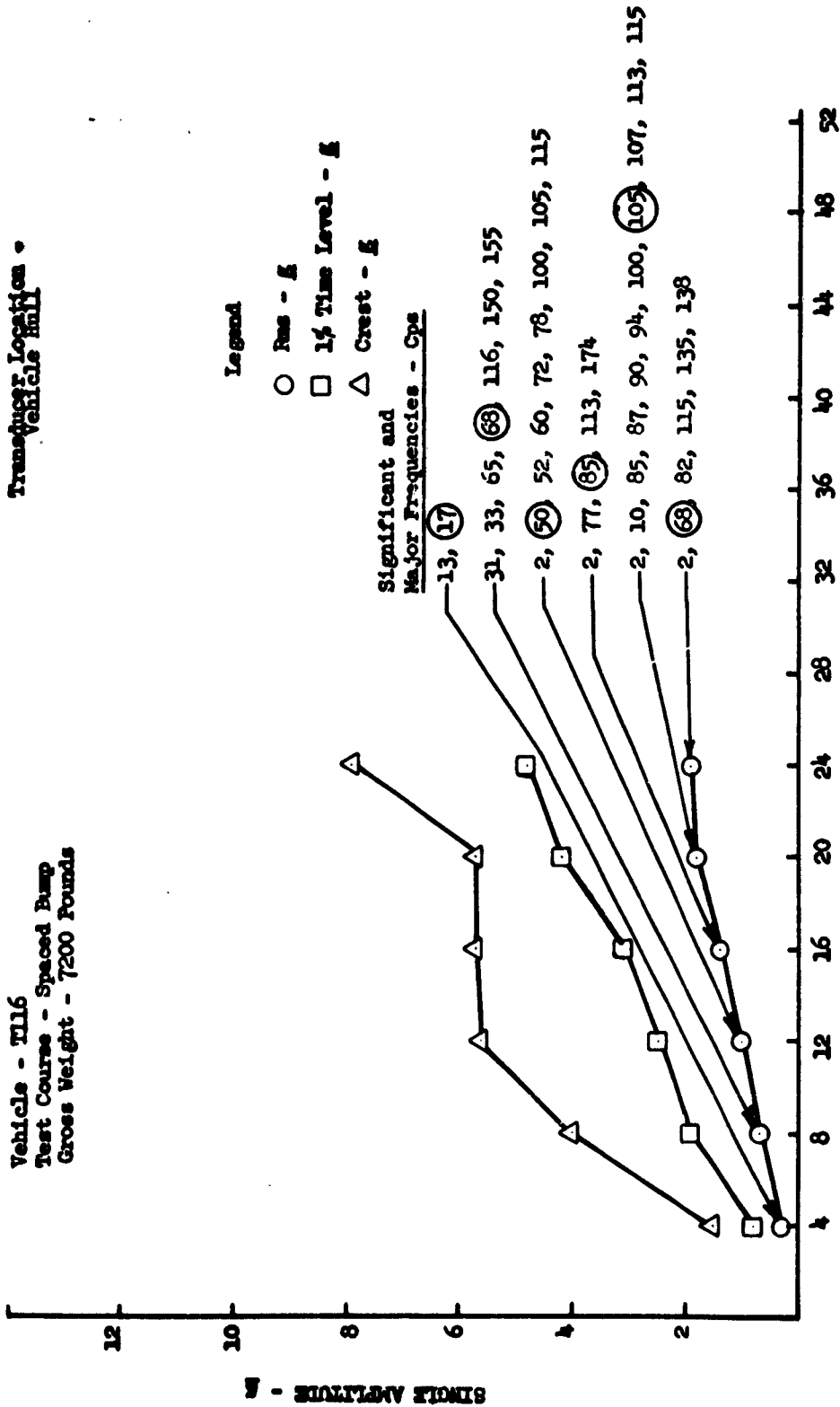
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
Test Course - Spaced Bump
Gross Weight - 7200 Pounds

Transducer Location -
Vehicle Rear



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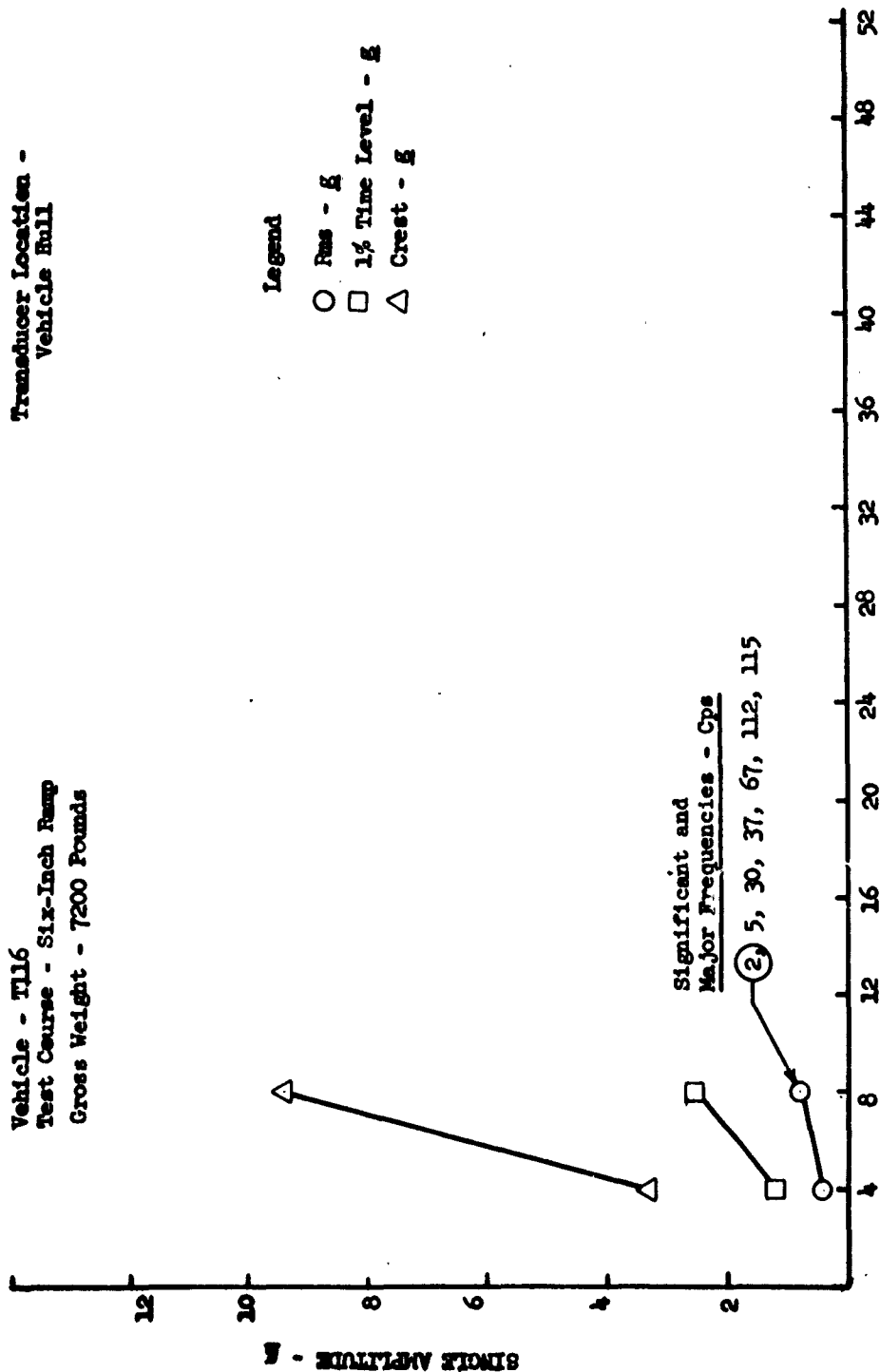
ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
Test Course - Six-Inch Ramp
Gross Weight - 7200 Pounds

Transducer Location -
Vehicle Hull



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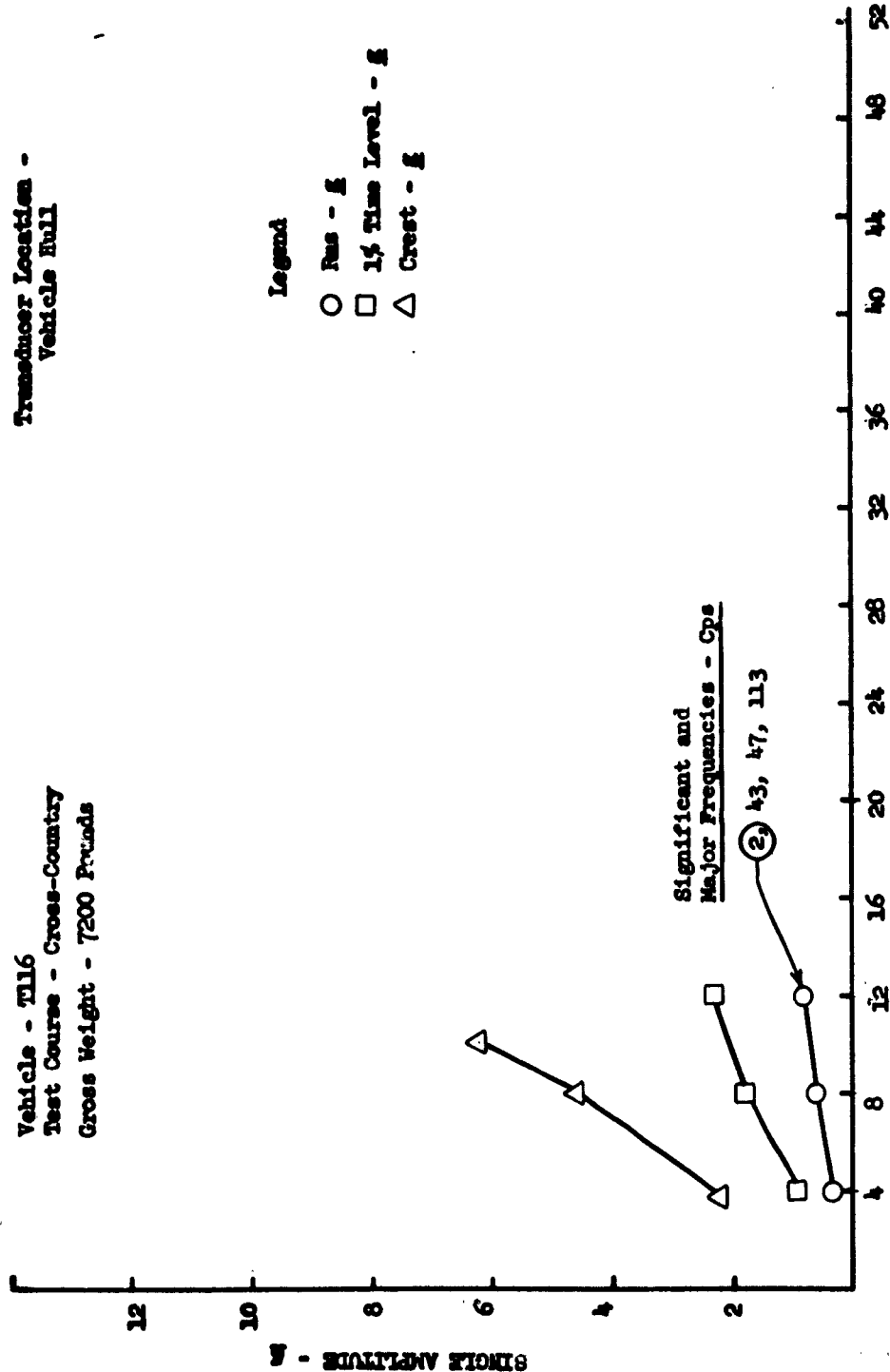
ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - T116
Test Course - Cross-Country
Gross Weight - 7200 Pounds

Transducer Location -
Vehicle Hull



ROAD SPEED - MPH

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VIORATION ENVIRONMENT (VERTICAL)

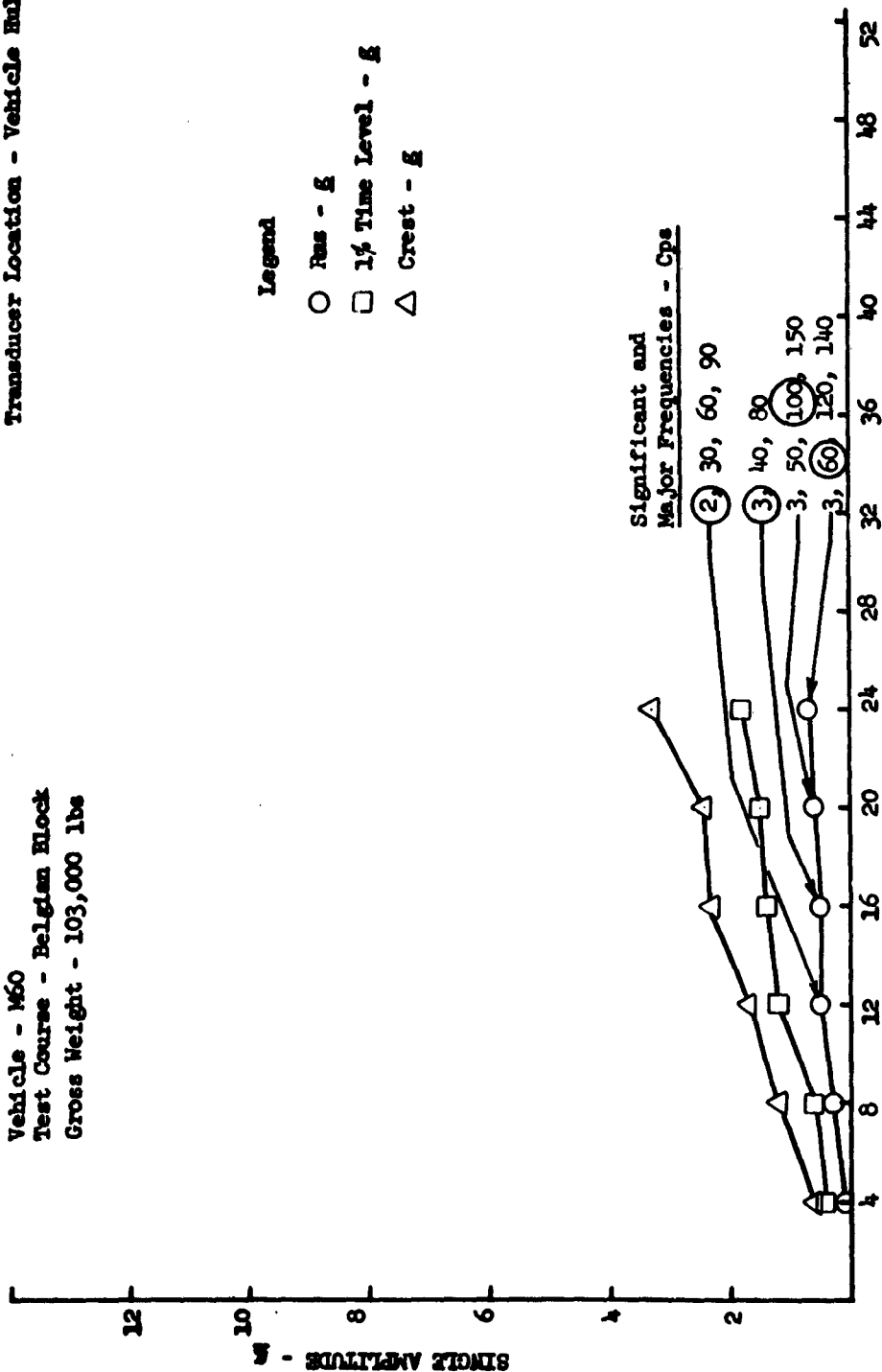
AMPLITUDE VS ROAD SPEED

Vehicle - M60
Test Course - Belgian Block
Gross Weight - 103,000 lbs

Transducer Location - Vehicle Roll

Legend

- Run - \bar{g}
- 1/2 Time Level - \bar{g}
- △ Crest - \bar{g}



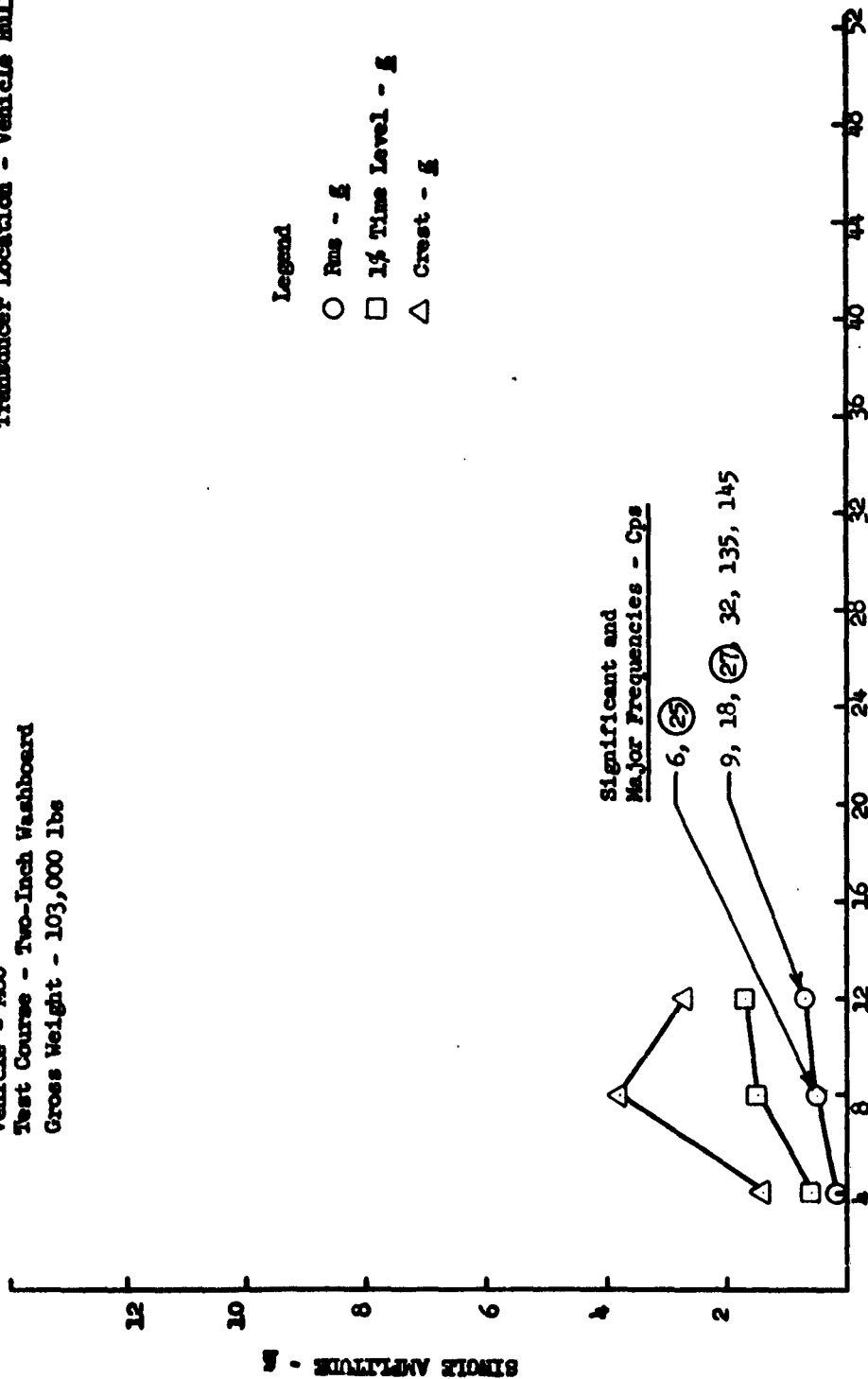
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M60
 Test Course - Two-Inch Washboard
 Gross Weight - 103,000 lbs

Transducer Location - Vehicle Hull



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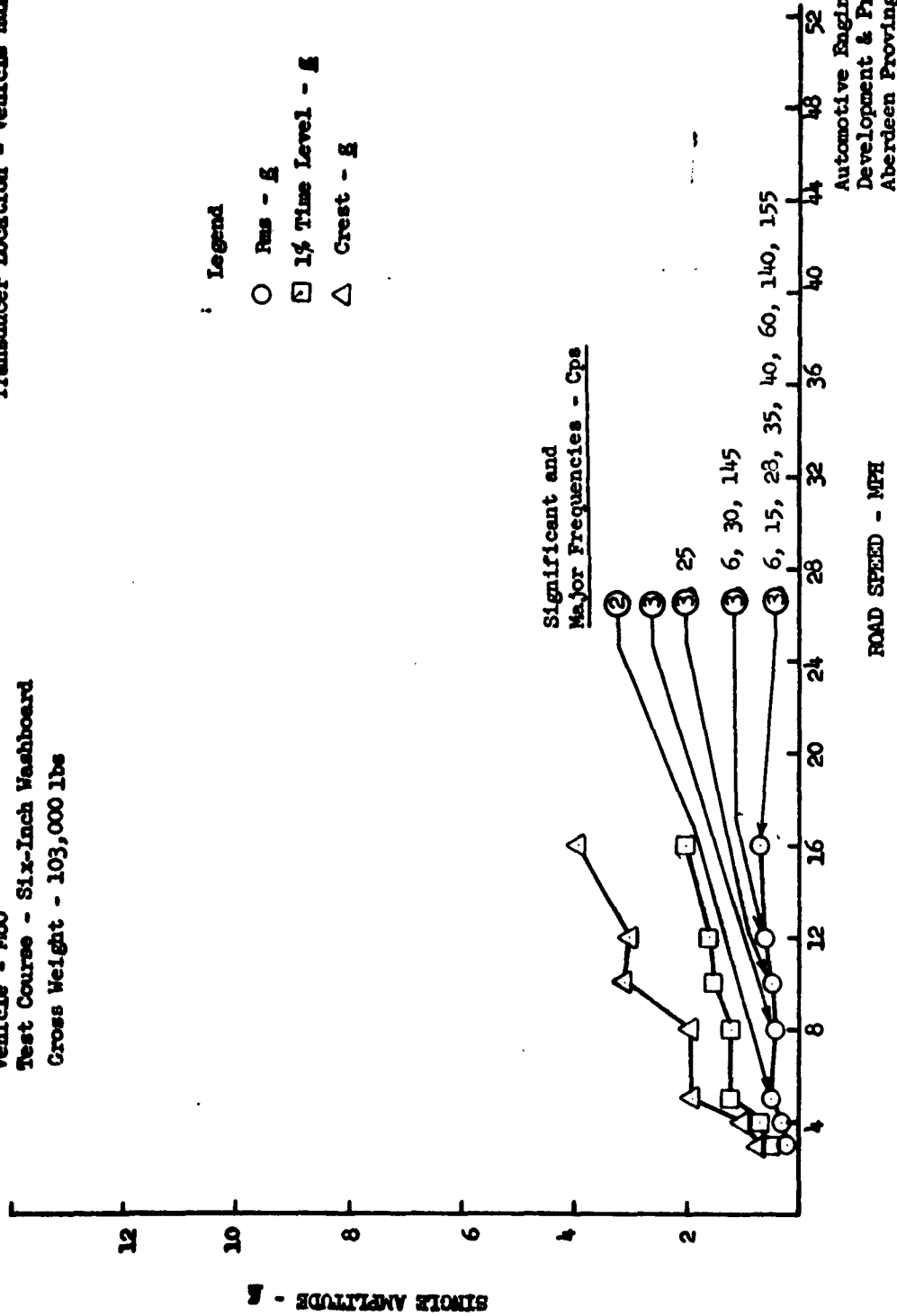
VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M60
 Test Course - Six-Inch Washboard
 Gross Weight - 103,000 lbs

Transducer Location - Vehicle Roll

- Legend
- Res - \bar{g}
 - 1% Time Level - \bar{g}
 - △ Crest - \bar{g}



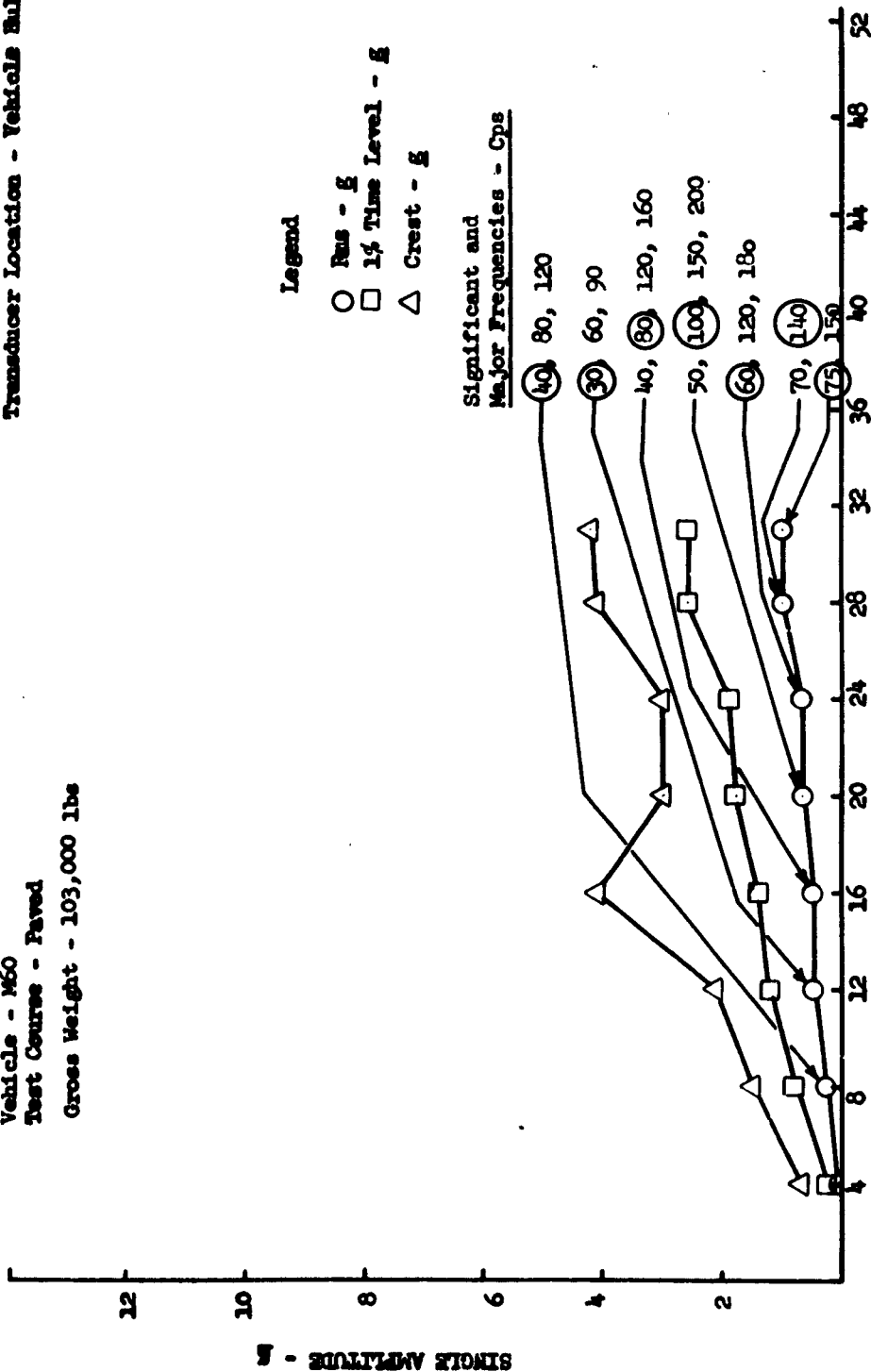
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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M60
 Test Course - Paved
 Gross Weight - 103,000 lbs

Transducer Location - Vehicle Hull



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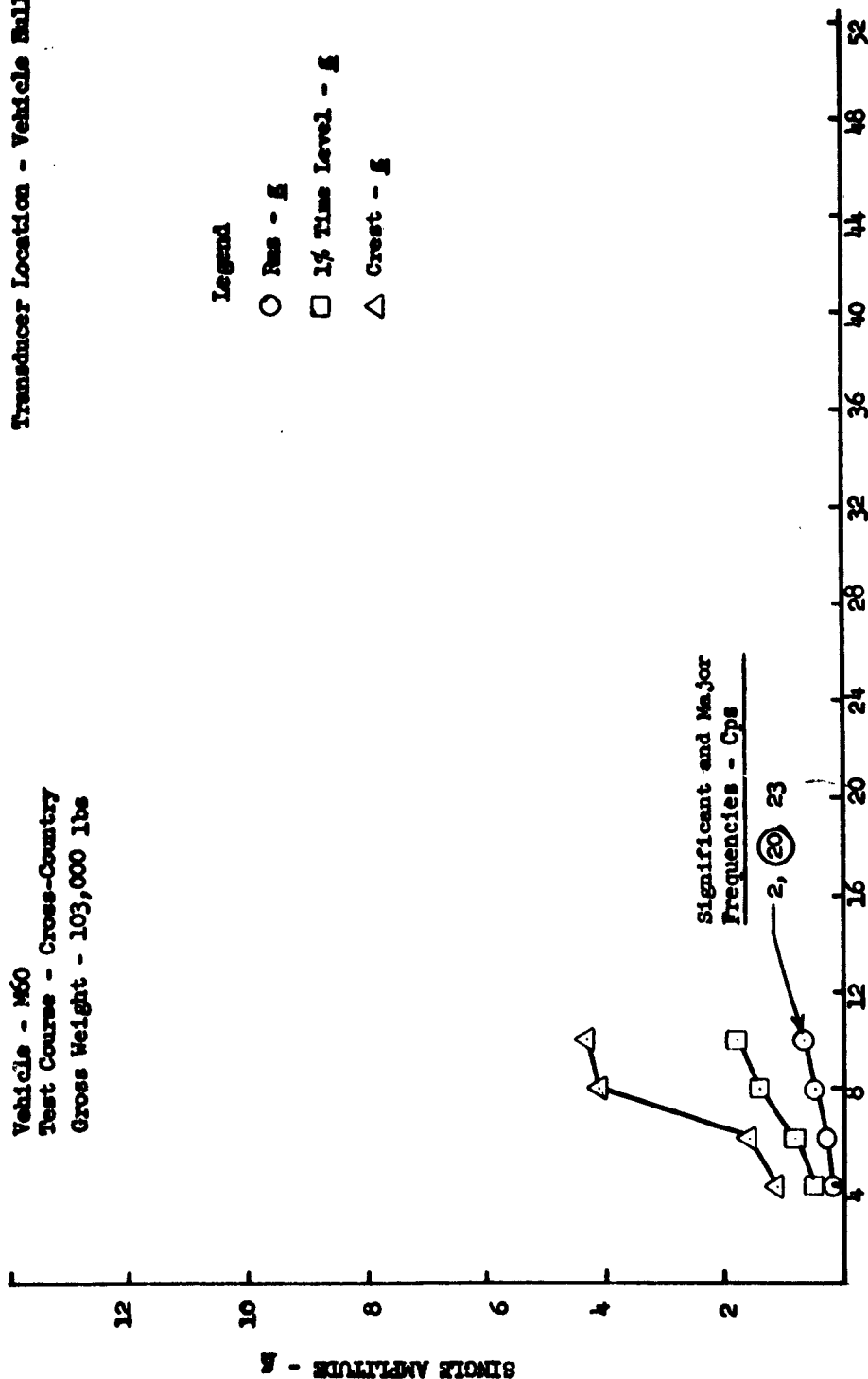
VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Transducer Location - Vehicle Ball

Vehicle - M60
Test Course - Cross-Country
Gross Weight - 103,000 lbs

- Legend
- Run - $\frac{1}{2}$
 - 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
 - △ Crest - $\frac{1}{2}$



ROAD SPEED - MPH

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VIBRATION ENVIRONMENT (VERTICAL)

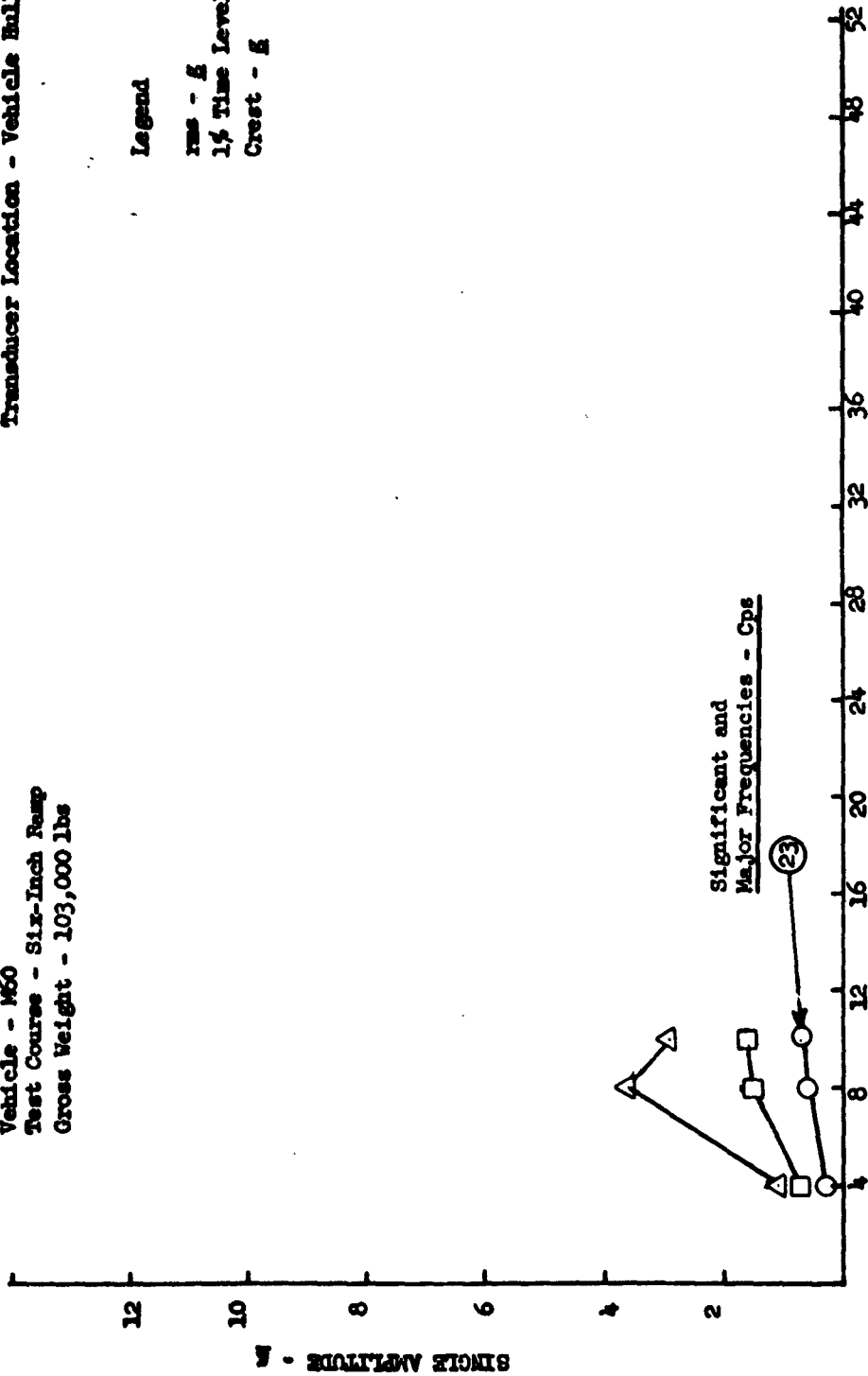
AMPLITUDE VS ROAD SPEED

Vehicle - M60
Test Course - Six-Inch Ramp
Gross Weight - 103,000 lbs

Transducer Location - Vehicle Hull

Legend

rms - \square
1/3 Time Level - \triangle
Crest - \circ



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ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

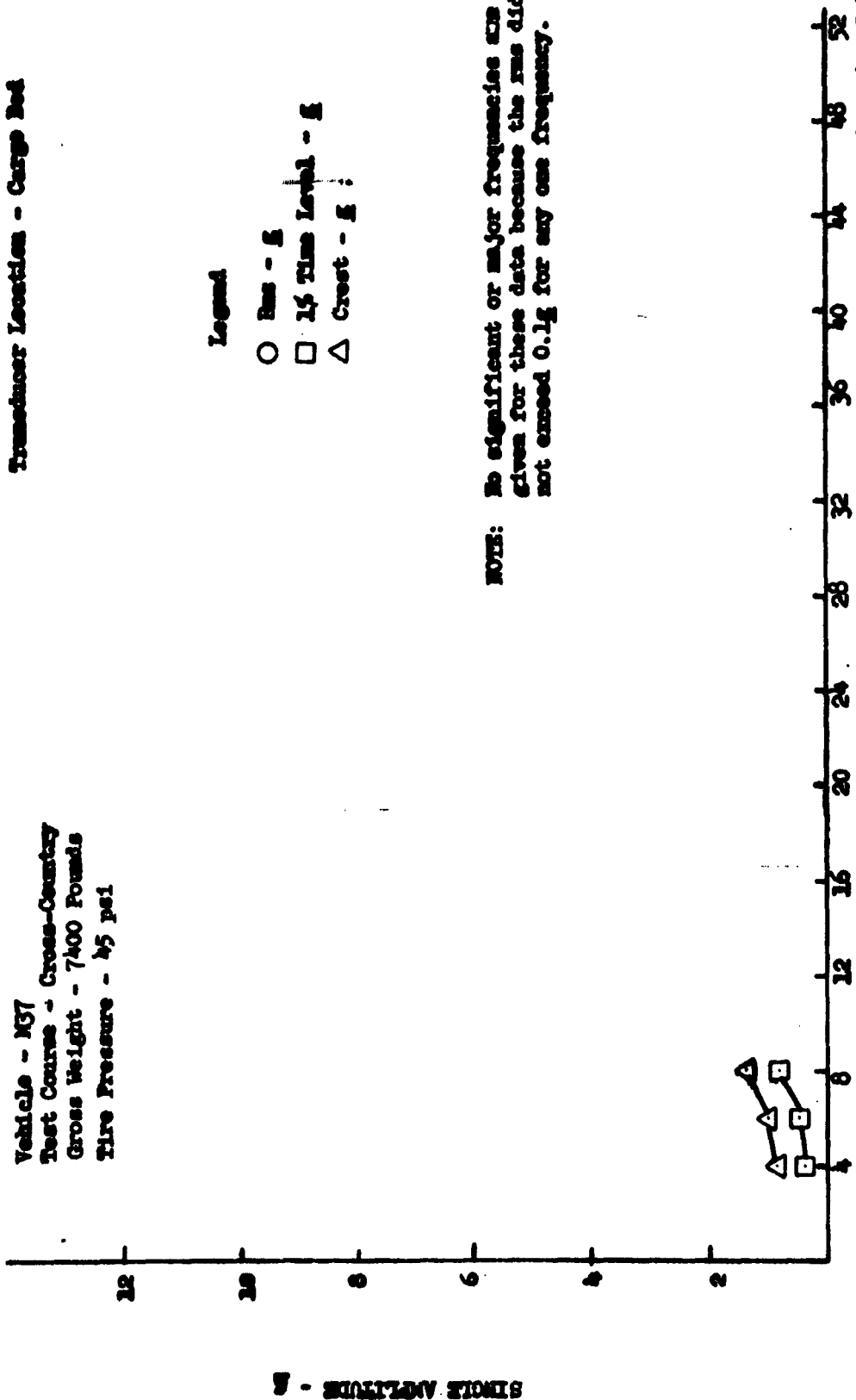
Truckload Location - Cargo Bed

Vehicle - M37
Test Course - Cross-Country
Gross Weight - 7400 Pounds
Tire Pressure - 45 psi

Legend

- Rms - $\frac{1}{2}$
- 15 Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$

NOTE: No significant or major frequencies are given for these data because the rms did not exceed 0.1g for any one frequency.



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ROAD SPEED - MPH

SINGLE AMPLITUDE - g

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

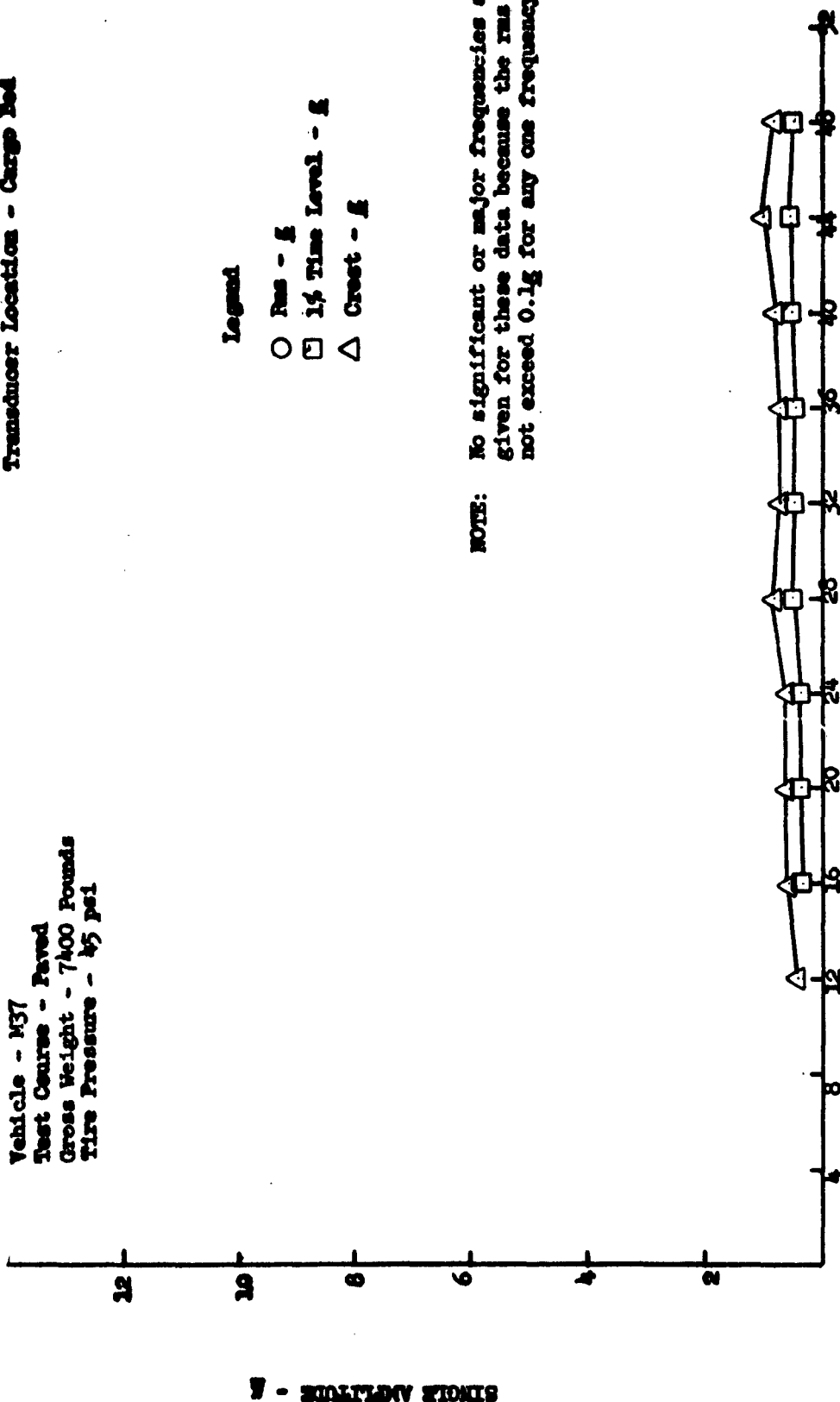
Transducer Location - Cargo Bed

Vehicle - M37
 Test Course - Paved
 Gross Weight - 7400 Pounds
 Tire Pressure - 45 psi

Legend

- Run - 1
- 1 1/2 Time Level - 1
- △ Crest - 1

NOTE: No significant or major frequencies are given for these data because the rms did not exceed 0.1g for any one frequency.



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ROAD SPEED - MPH

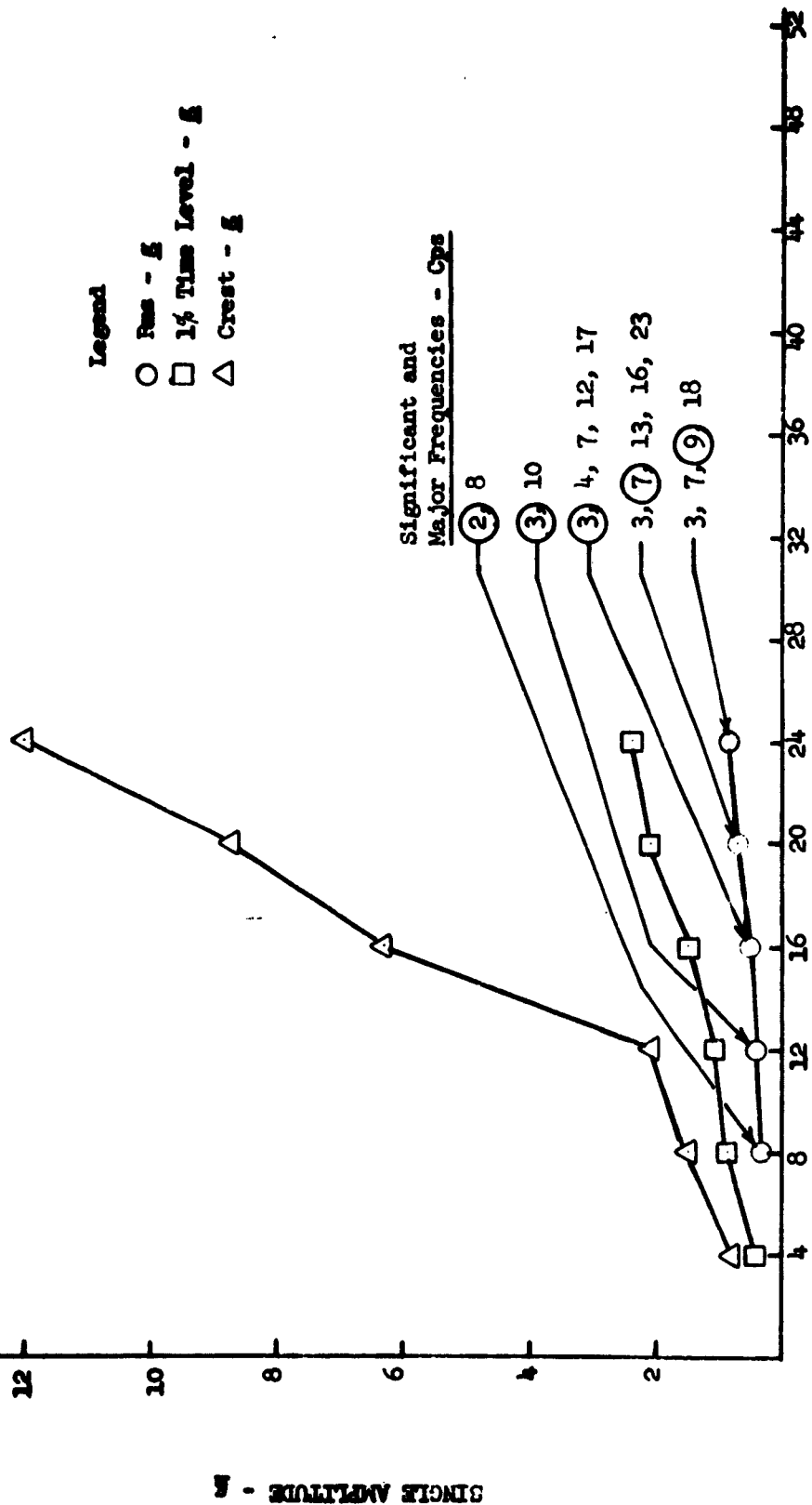
SINGLE AMPLITUDE - g

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M37
 Test Course - Spaced Bump
 Gross Weight - 7400 Pounds
 Tire Pressure - 45 psi

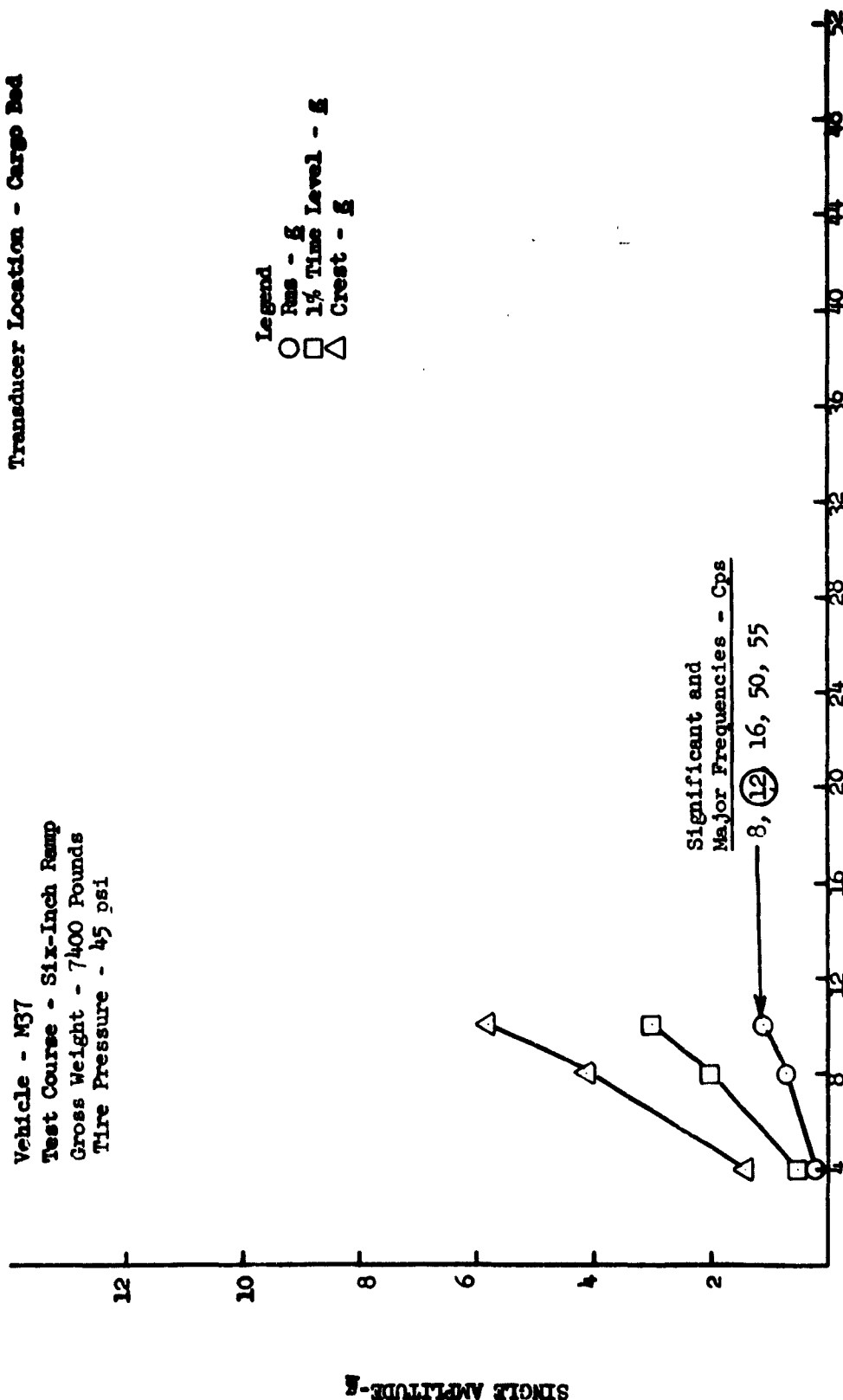


VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M37
 Test Course - Six-Inch Ramp
 Gross Weight - 7400 Pounds
 Tire Pressure - 45 psi



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ROAD SPEED - MPH

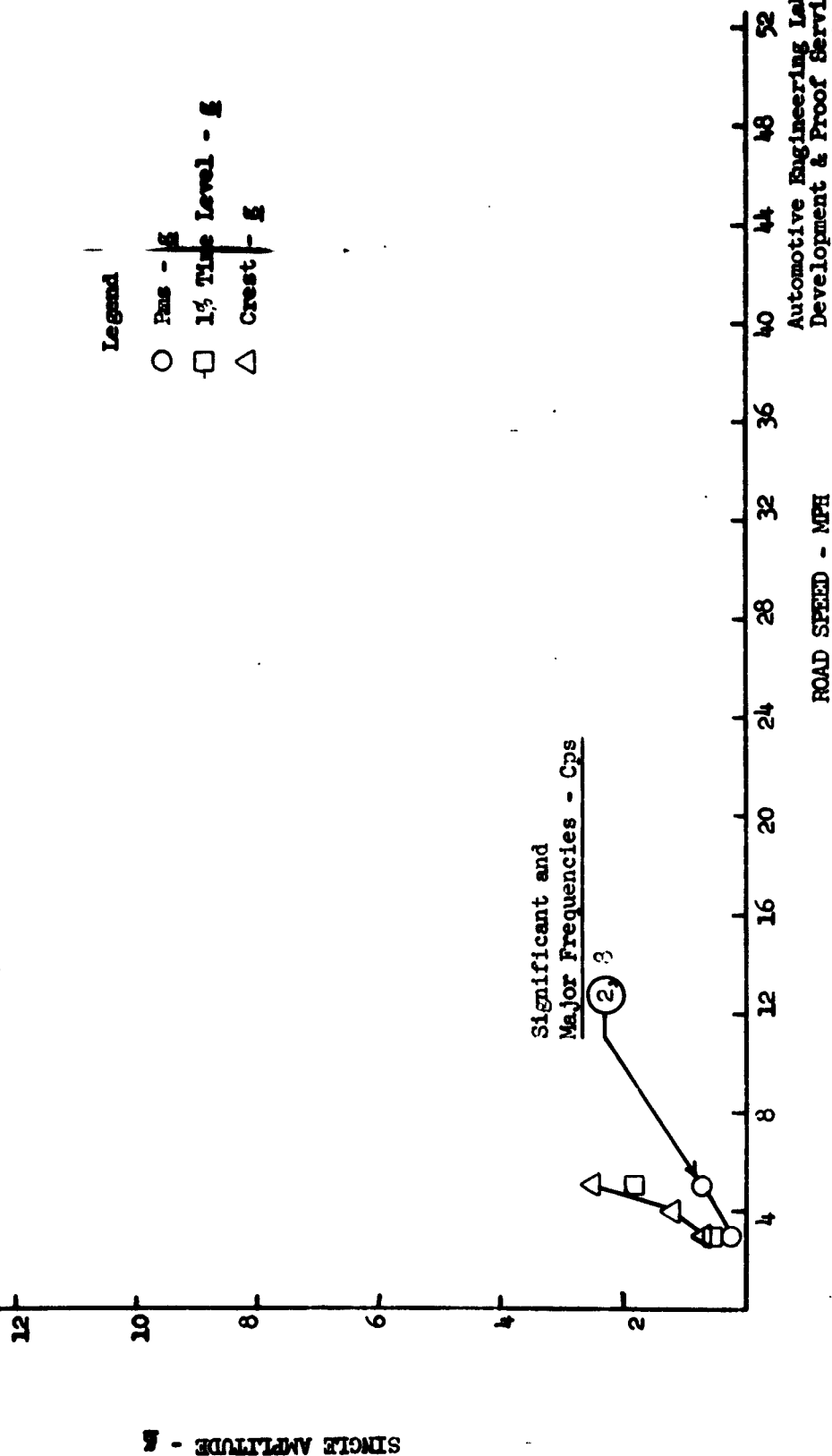
SINGLE AMPLITUDE - g

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M37
 Test Course - Six-Inch Washboard
 Gross Weight - 7400 Pounds
 Tire Pressure - 45 psi

Transducer Location - Cargo Bed



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VIBRATION ENVIRONMENT (VERTICAL)

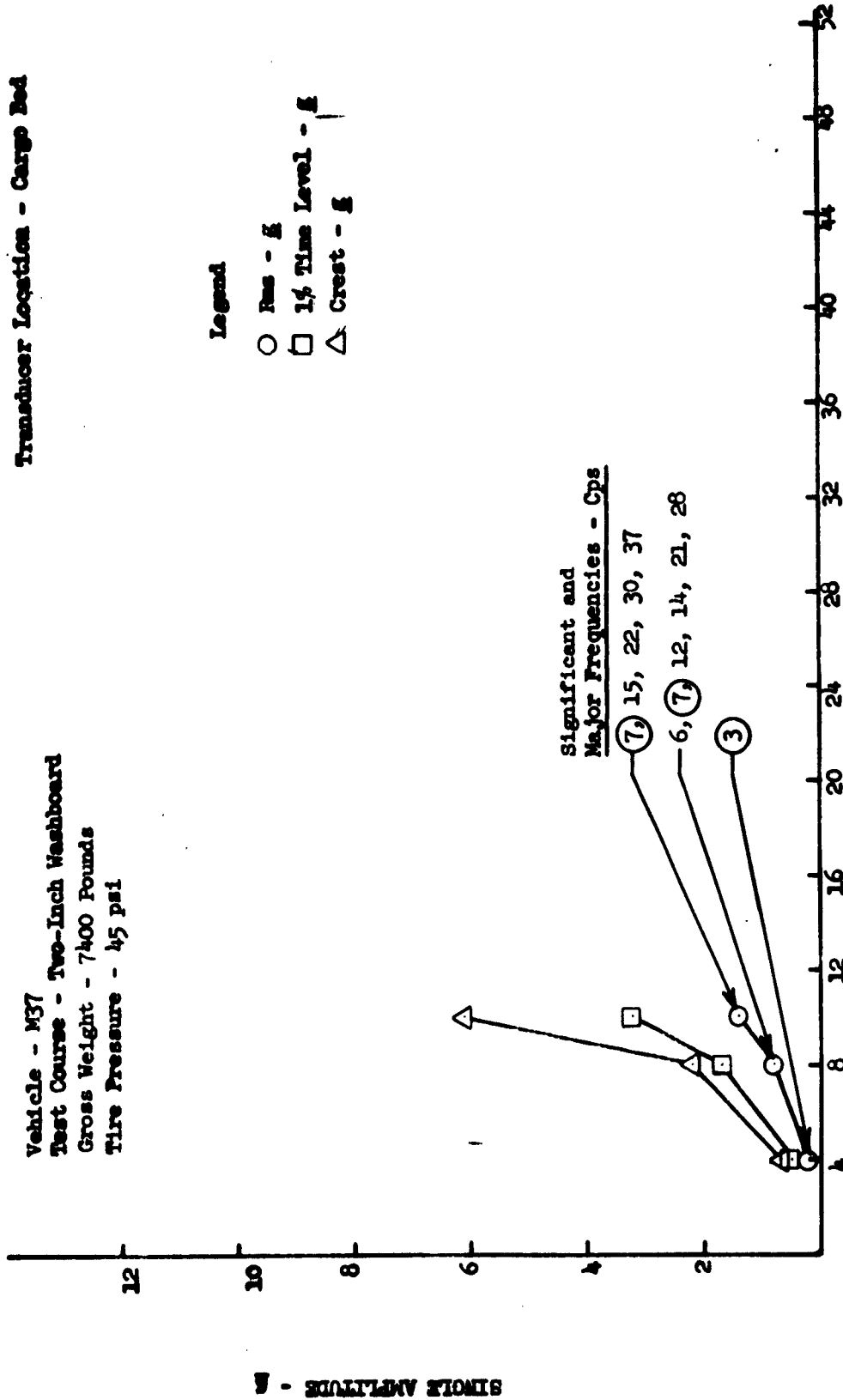
AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M37
 Test Course - Two-Inch Washboard
 Gross Weight - 7400 Pounds
 Tire Pressure - 45 psi

Legend

- Res - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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 GH10b/mc/4 September 1962

VIBRATION ENVIRONMENT (VERTICAL)

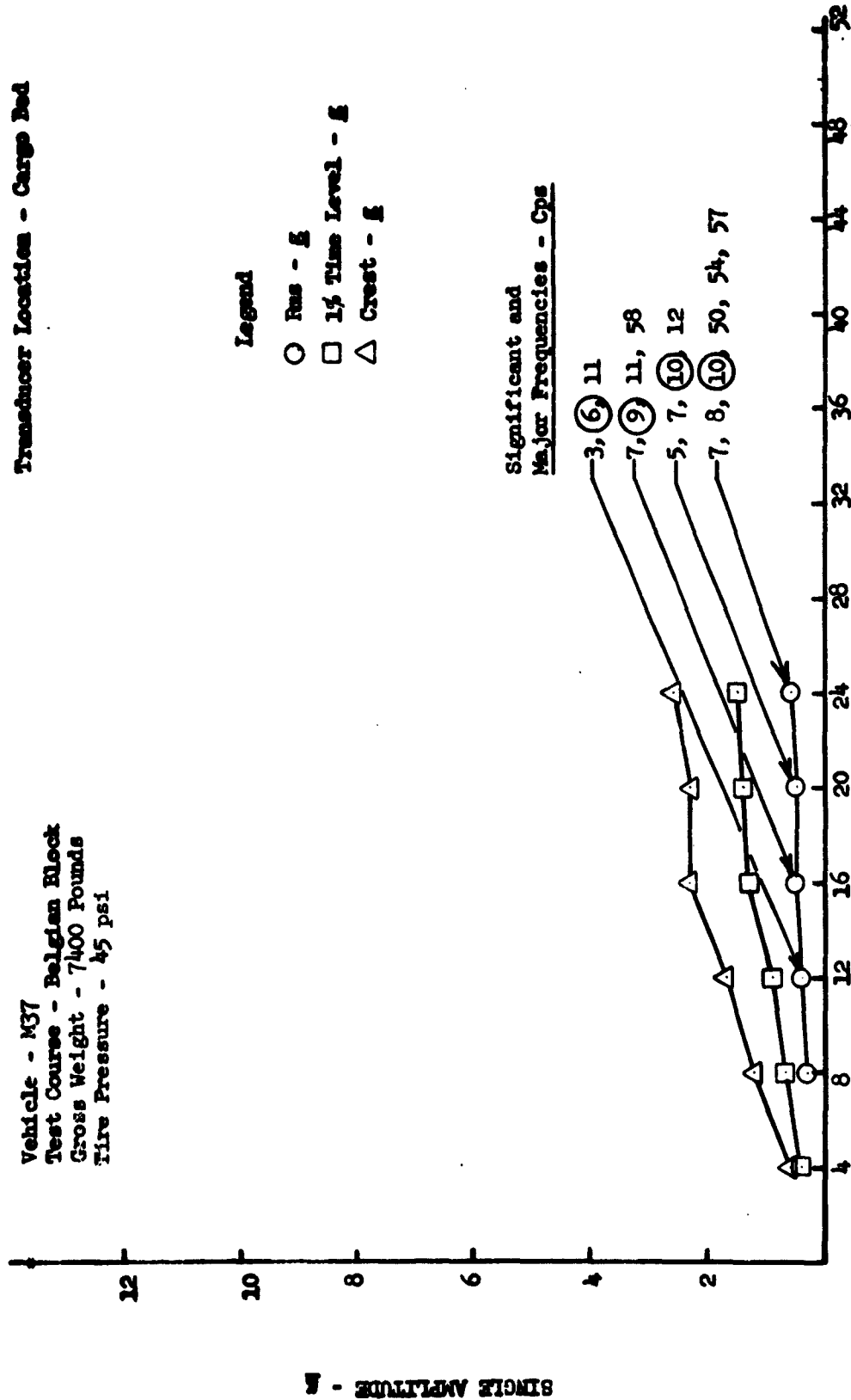
AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M37
 Test Course - Belgian Block
 Gross Weight - 7400 Pounds
 Tire Pressure - 45 psi

Legend

- Run - \bar{x}
- 1 $\frac{1}{2}$ Time Level - \bar{x}
- △ Crest - \bar{x}



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VIBRATION ENVIRONMENT (VERTICAL)

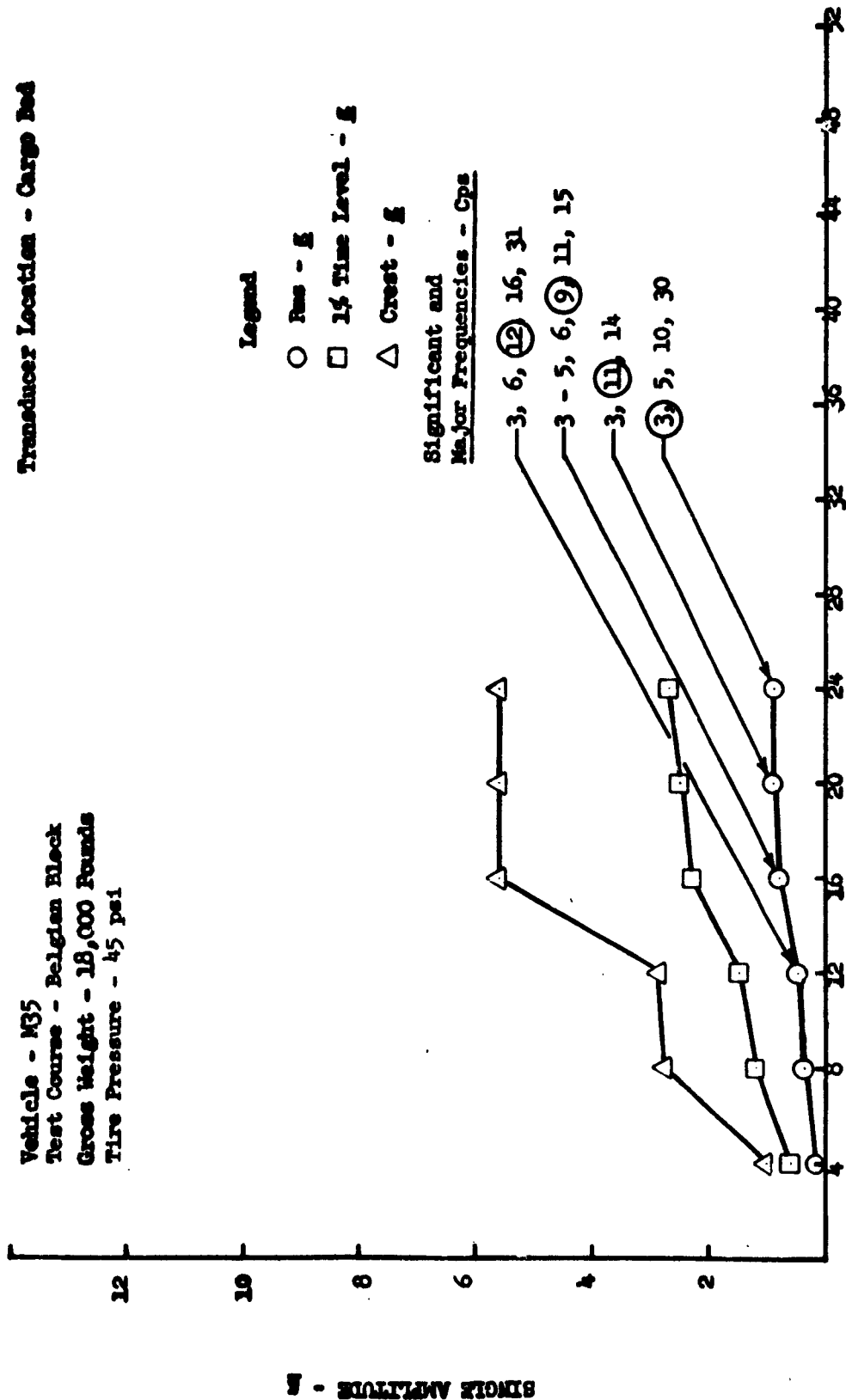
AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M35
 Test Course - Belgian Block
 Gross Weight - 18,000 Pounds
 Tire Pressure - 45 psi

- Legend**
- Run - 8
 - 14 Time Level - 8
 - △ Crest - 8

Significant and
 Major Frequencies - Cps

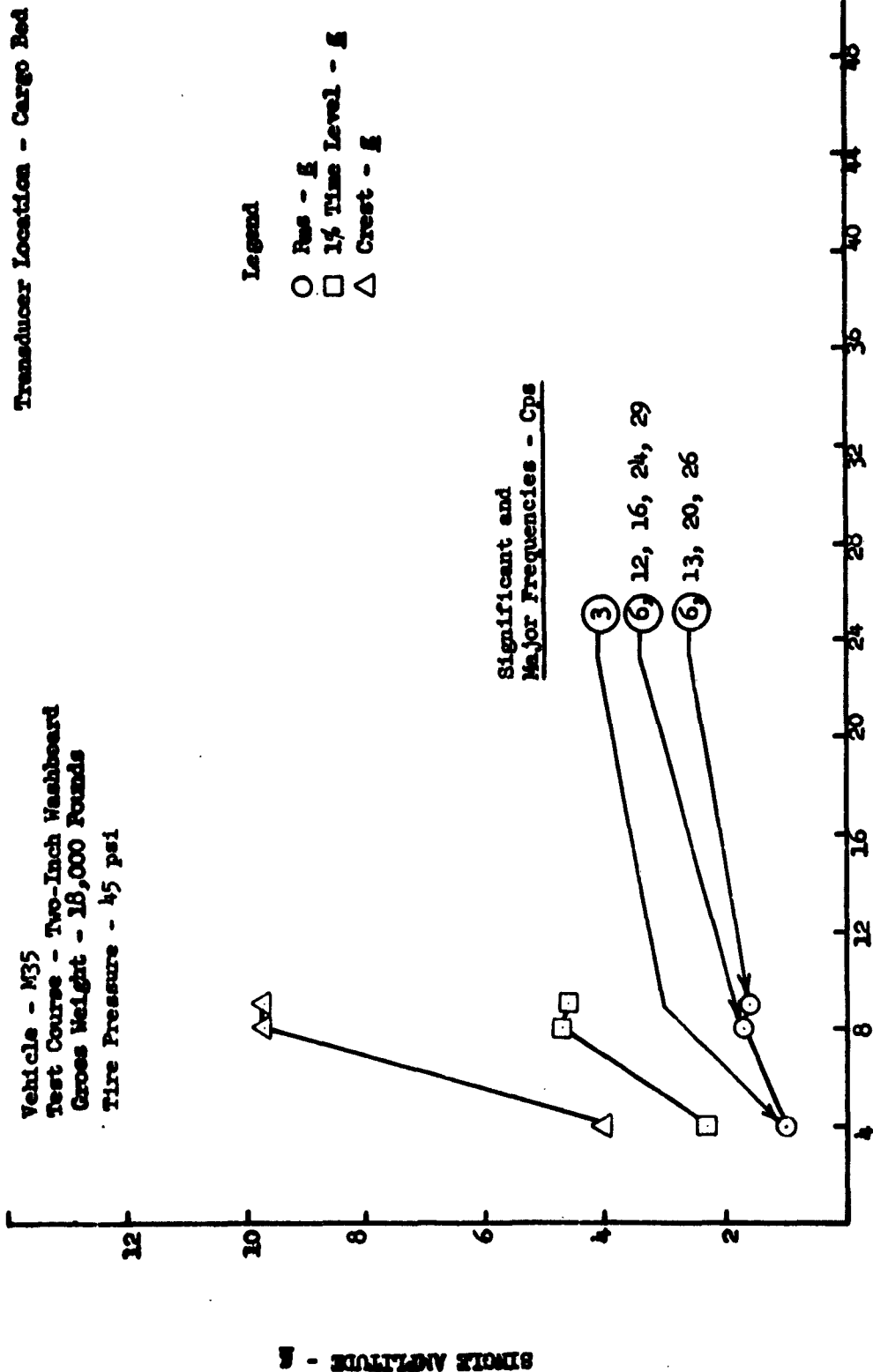


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ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED



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ROAD SPEED - MPH

VIBRATION ENVIRONMENT (VERTICAL)

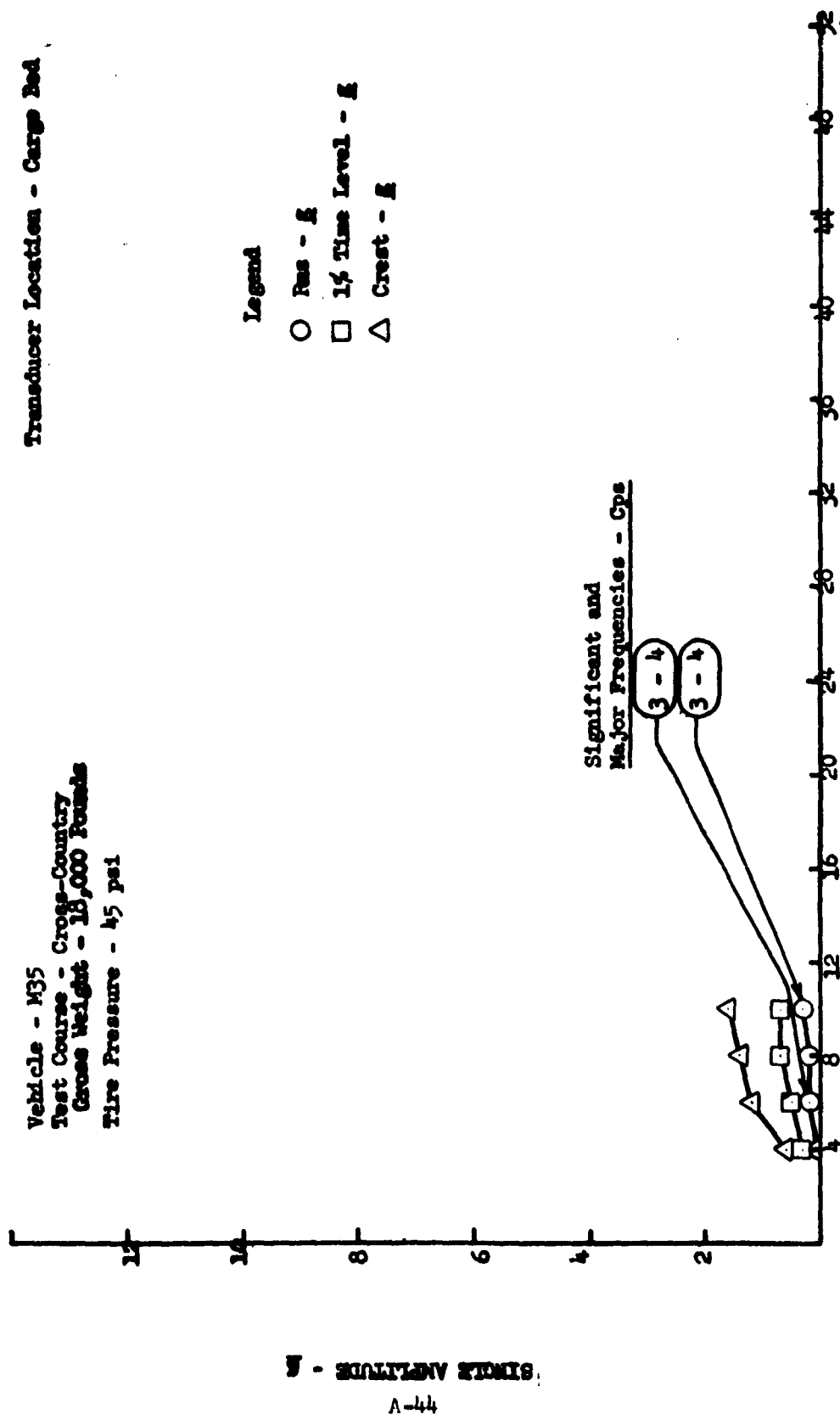
AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M35
 Test Course - Cross-Country
 Gross Weight - 18,000 Pounds
 Tire Pressure - 45 psi

Legend

- Pass - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



Significant and
 Major Frequencies - Cps

ROAD SPEED - MPH

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44 - V

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - M35
 Test Course - Paved
 Gross Weight - 18,000 Pounds
 Tire Pressure - 45 psi

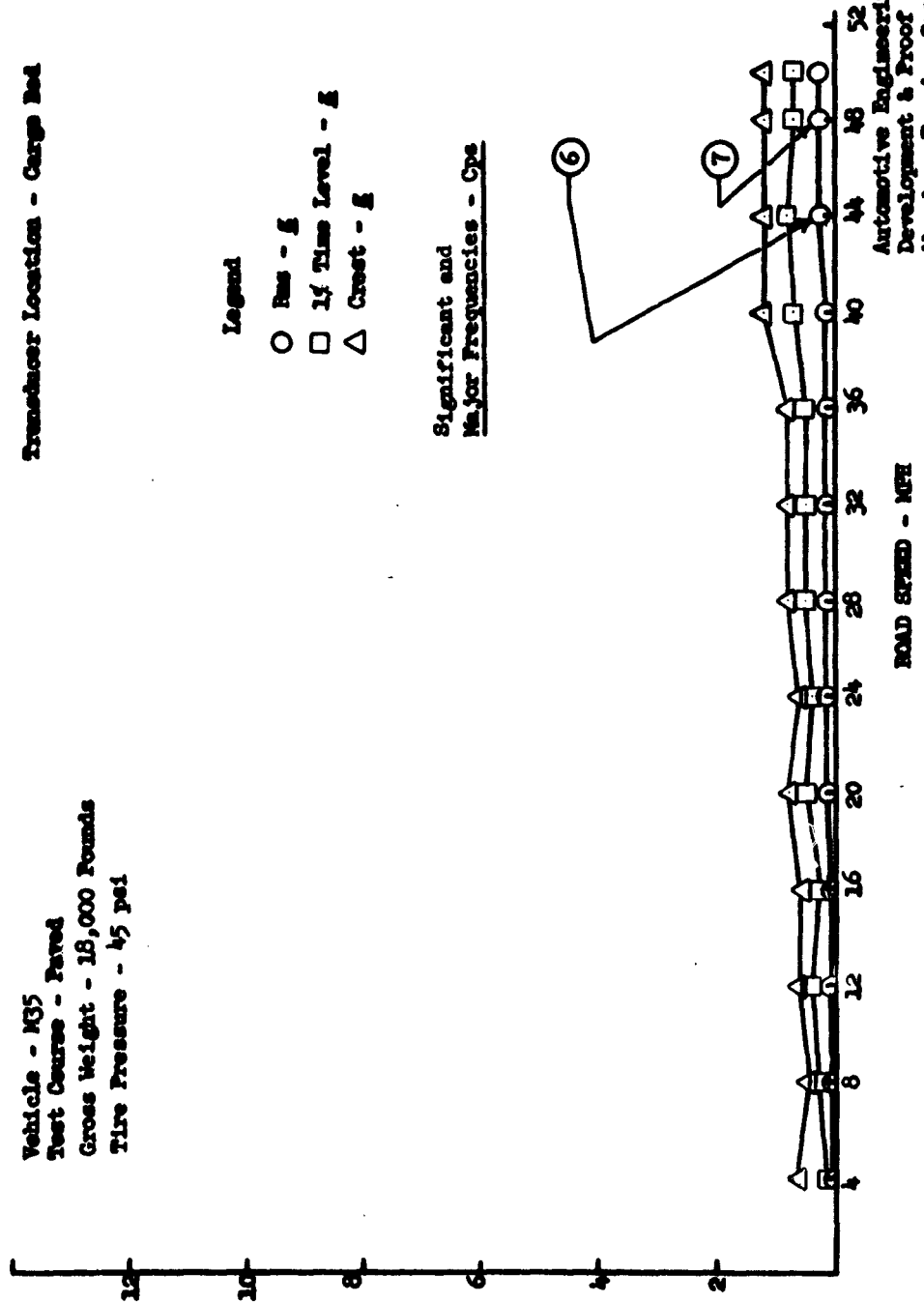
Transducer Location - Cargo Bed

SINGLE AMPLITUDE - g

Legend

- Run - g
- 1/4 Time Level - g
- △ Crest - g

Significant and
 Major Frequencies - Cps



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VEHICLE ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

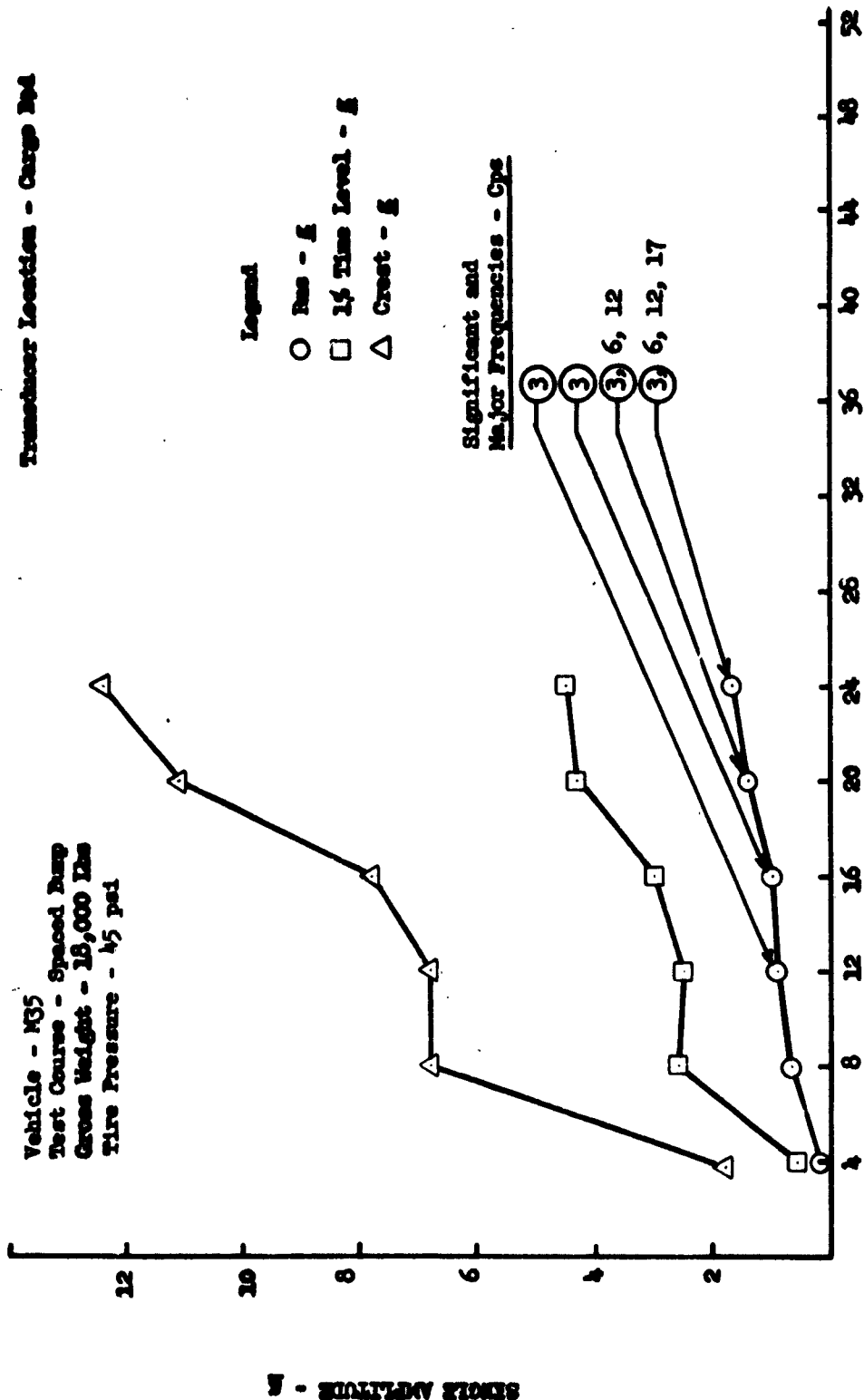
Transducer Location - Cargo Bed

Vehicle - M35
Test Course - Spaced Dump
Gross Weight - 18,000 lbs
Tire Pressure - 45 psi

Legend

- Bus - $\frac{1}{2}$
- 1 1/2 Tons Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$

Significant and
Major Frequencies - Cps



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ROAD SPEED - MPH

SEMI-AMPLITUDE - $\frac{1}{2}$

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

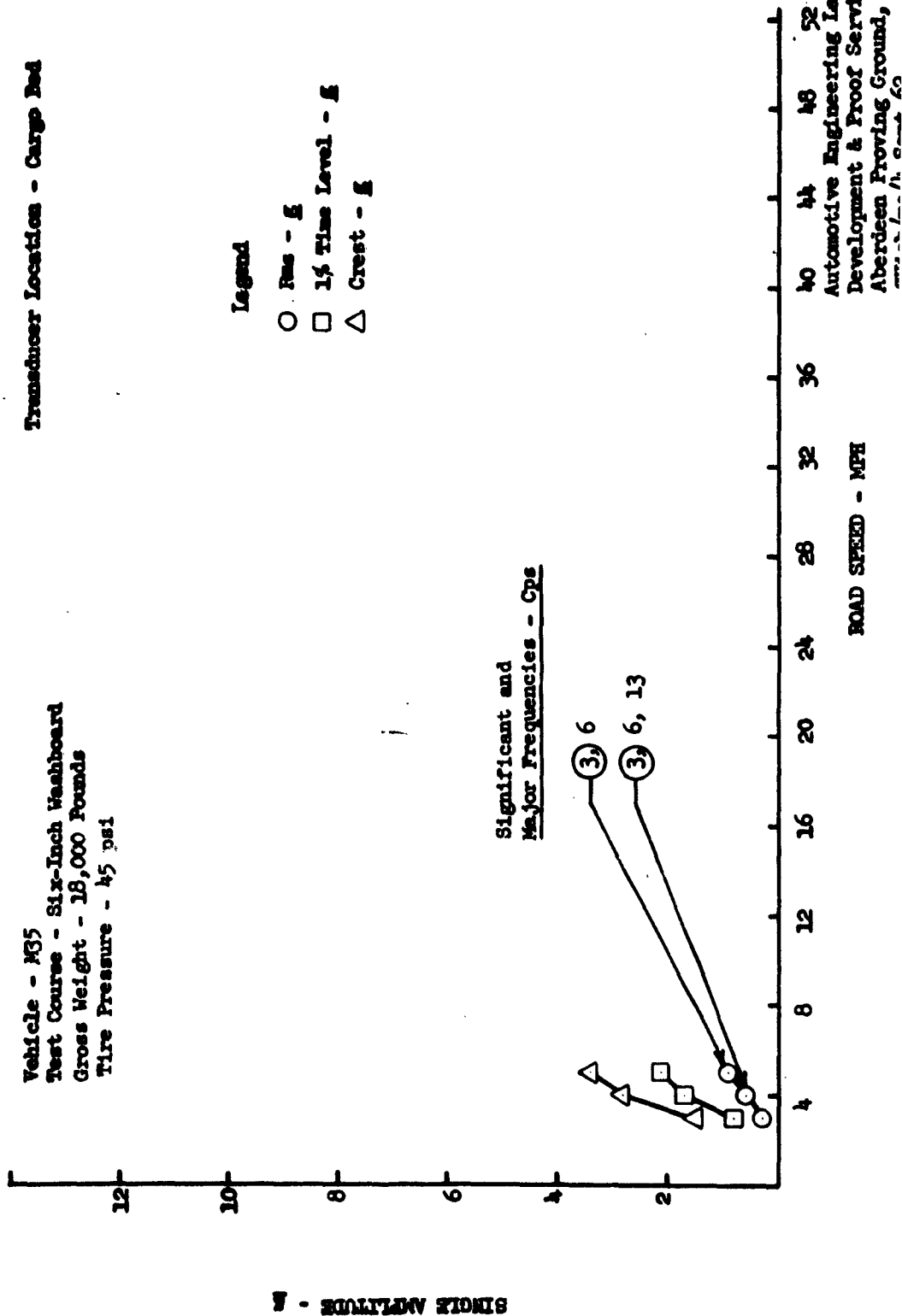
Vehicle - M35
Test Course - Six-Inch Washboard
Gross Weight - 18,000 Pounds
Tire Pressure - 45 psi

Transducer Location - Cargo Bed

Legend

- Run - 1
- 1/4 Time Level - 1
- △ Crest - 1

Significant and
Major Frequencies - Cps



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VIBRATION ENVIRONMENT (VERTICAL)

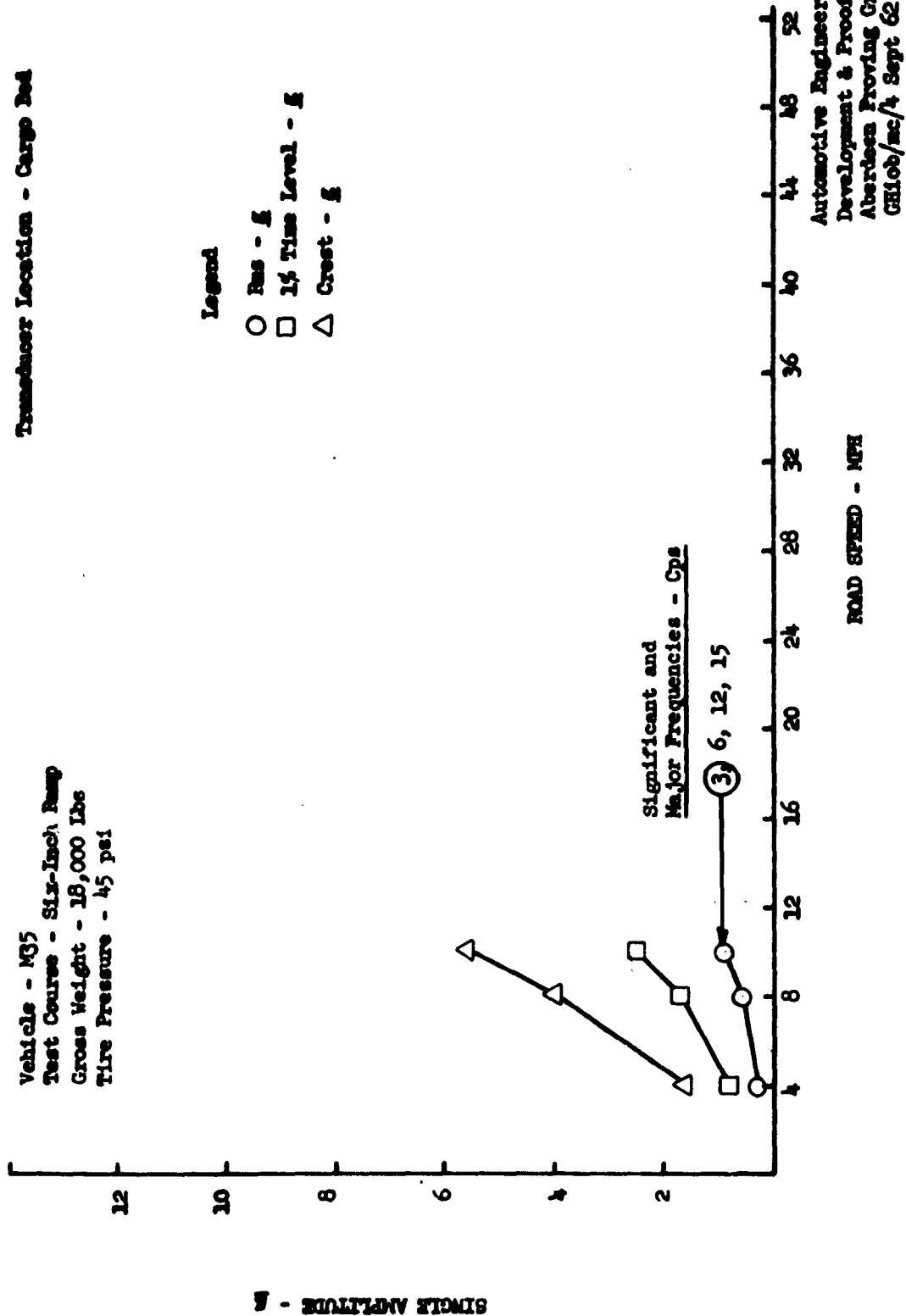
AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - M35
 Test Course - Six-Inch Ramp
 Gross Weight - 18,000 lbs
 Tire Pressure - 45 psi

Legend

- Bas - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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 GH10b/mc/4 Sept 62

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM410

Test Course - Paved

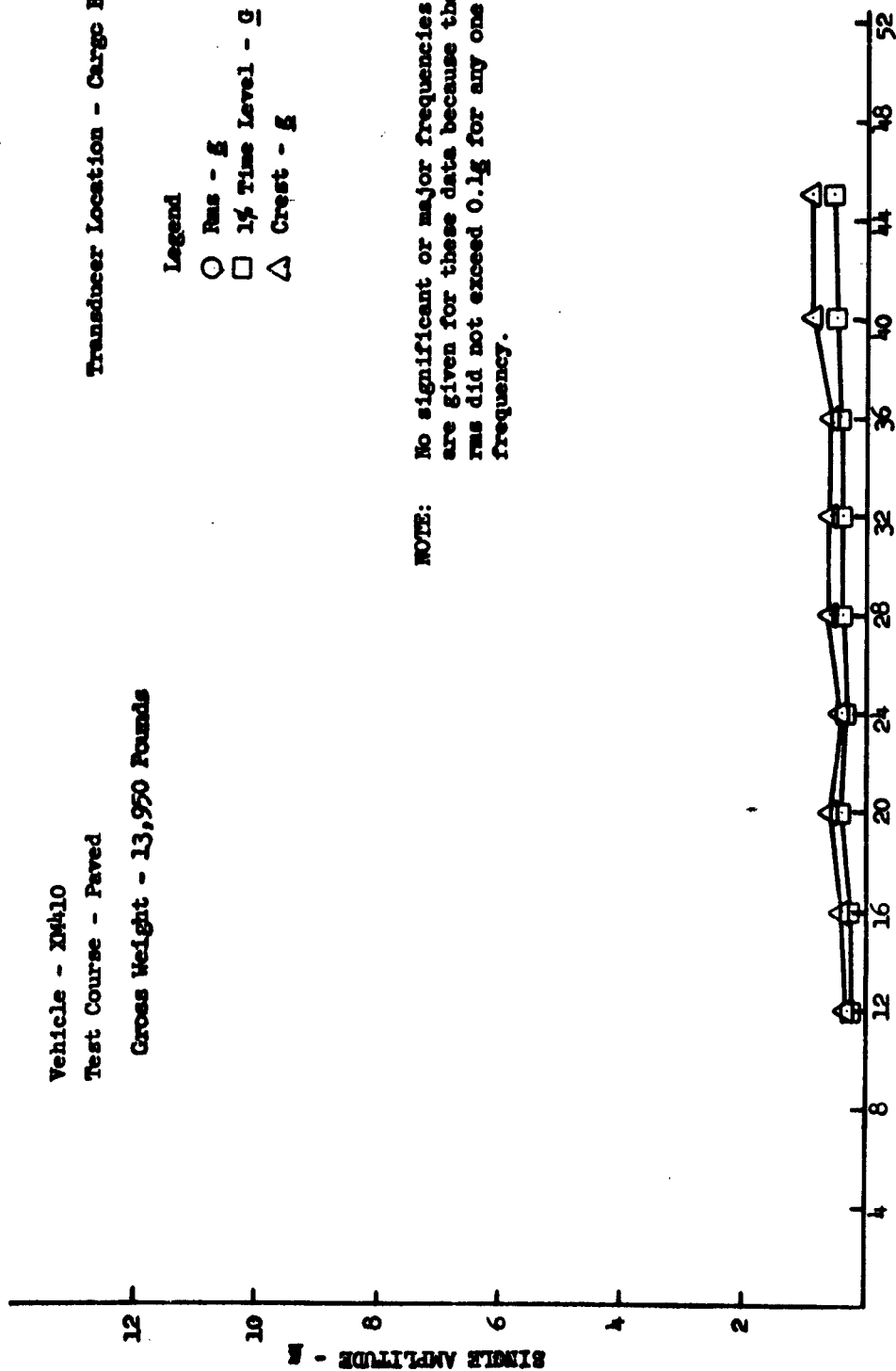
Gross Weight - 13,950 Pounds

Transducer Location - Cargo Bed

Legend

- Rms - \bar{g}
- 1 $\frac{1}{2}$ Time Level - \bar{g}
- △ Crest - \bar{g}

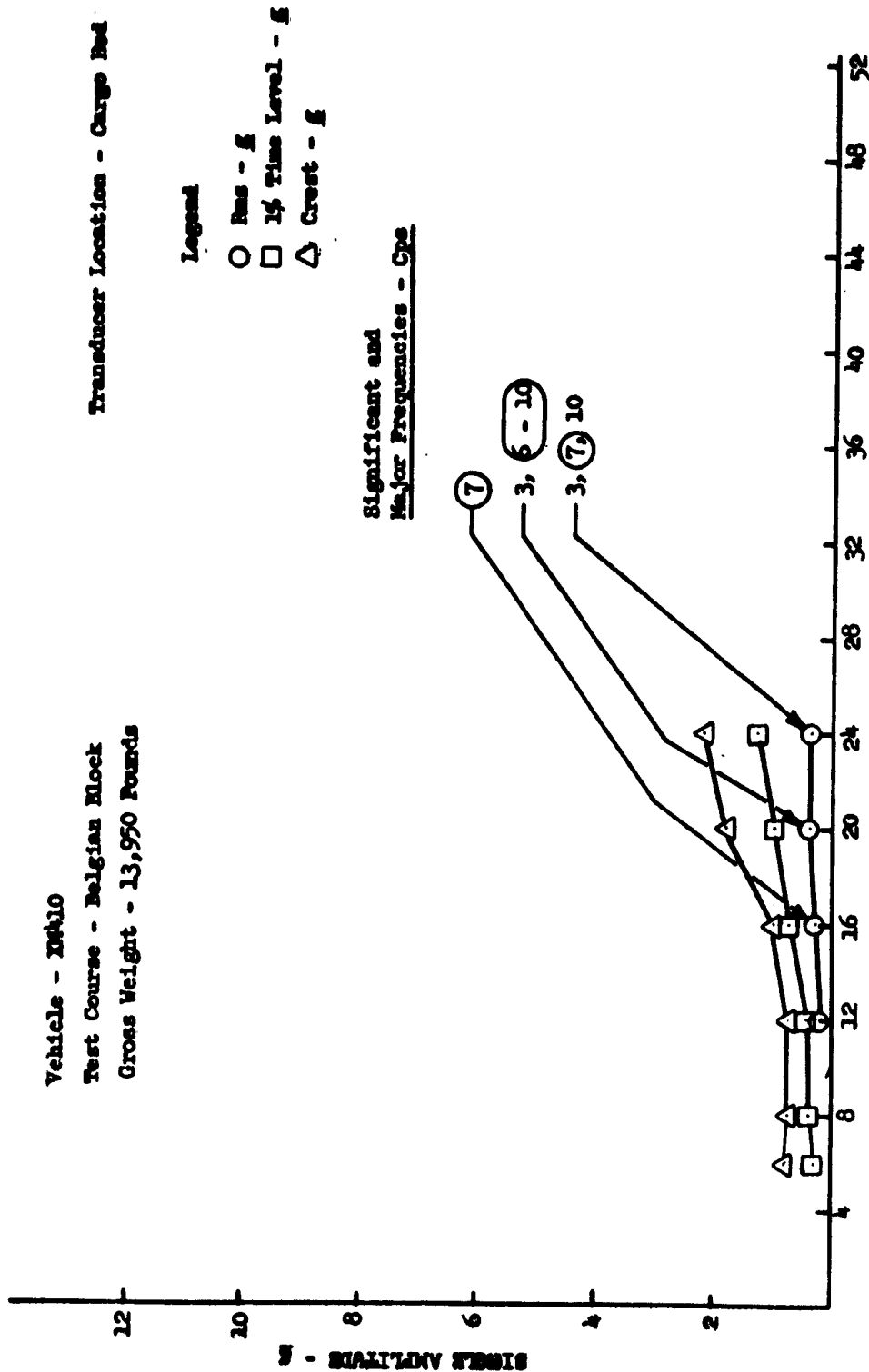
NOTE: No significant or major frequencies are given for these data because the rms did not exceed 0.1g for any one frequency.



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CH10b/mc/4 Sept 62

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED



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 GRI/mb/mc/4 Sept 62

VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM410

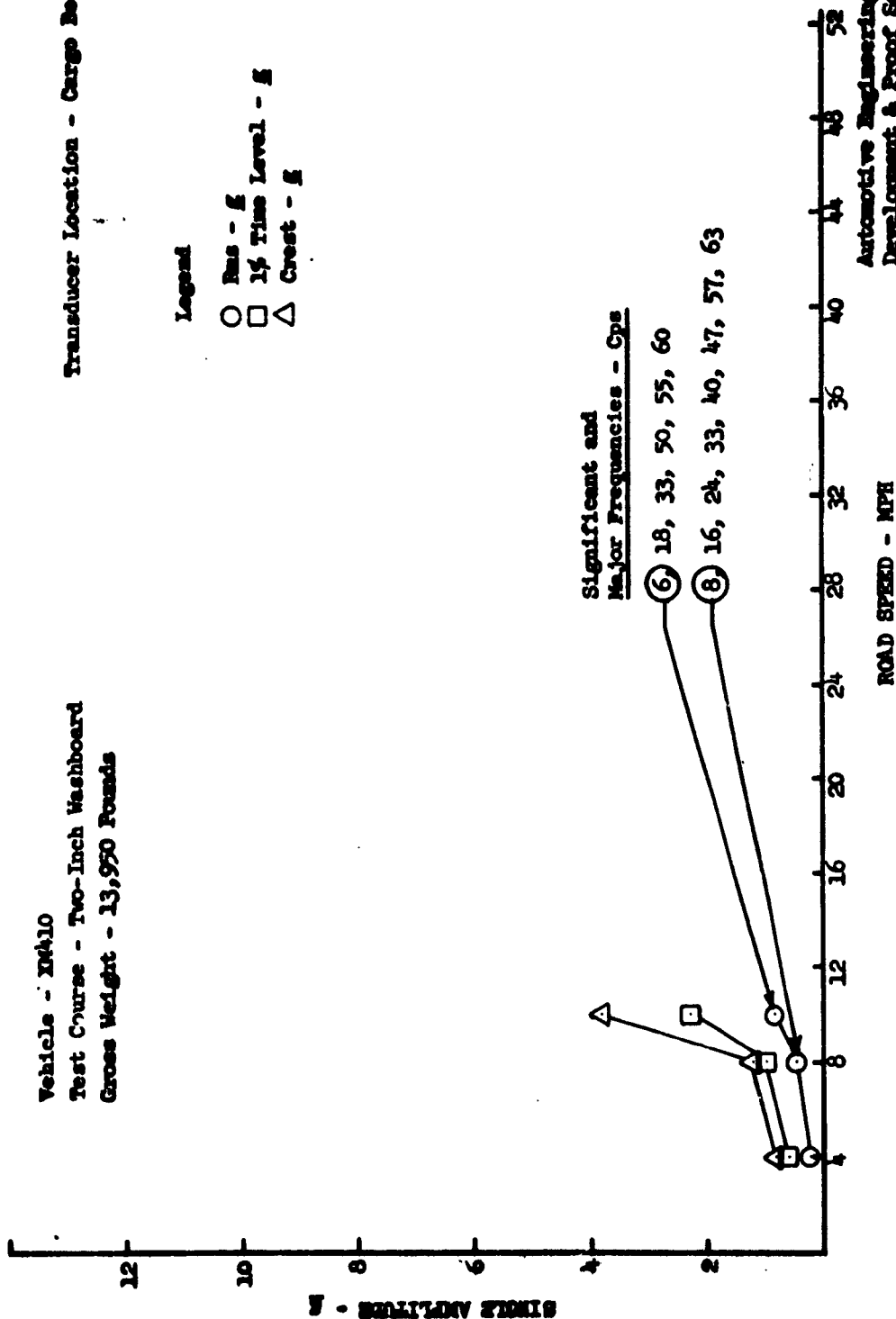
Test Course - Two-Inch Washboard

Gross Weight - 13,950 Pounds

Transducer Location - Cargo Bed

Legend

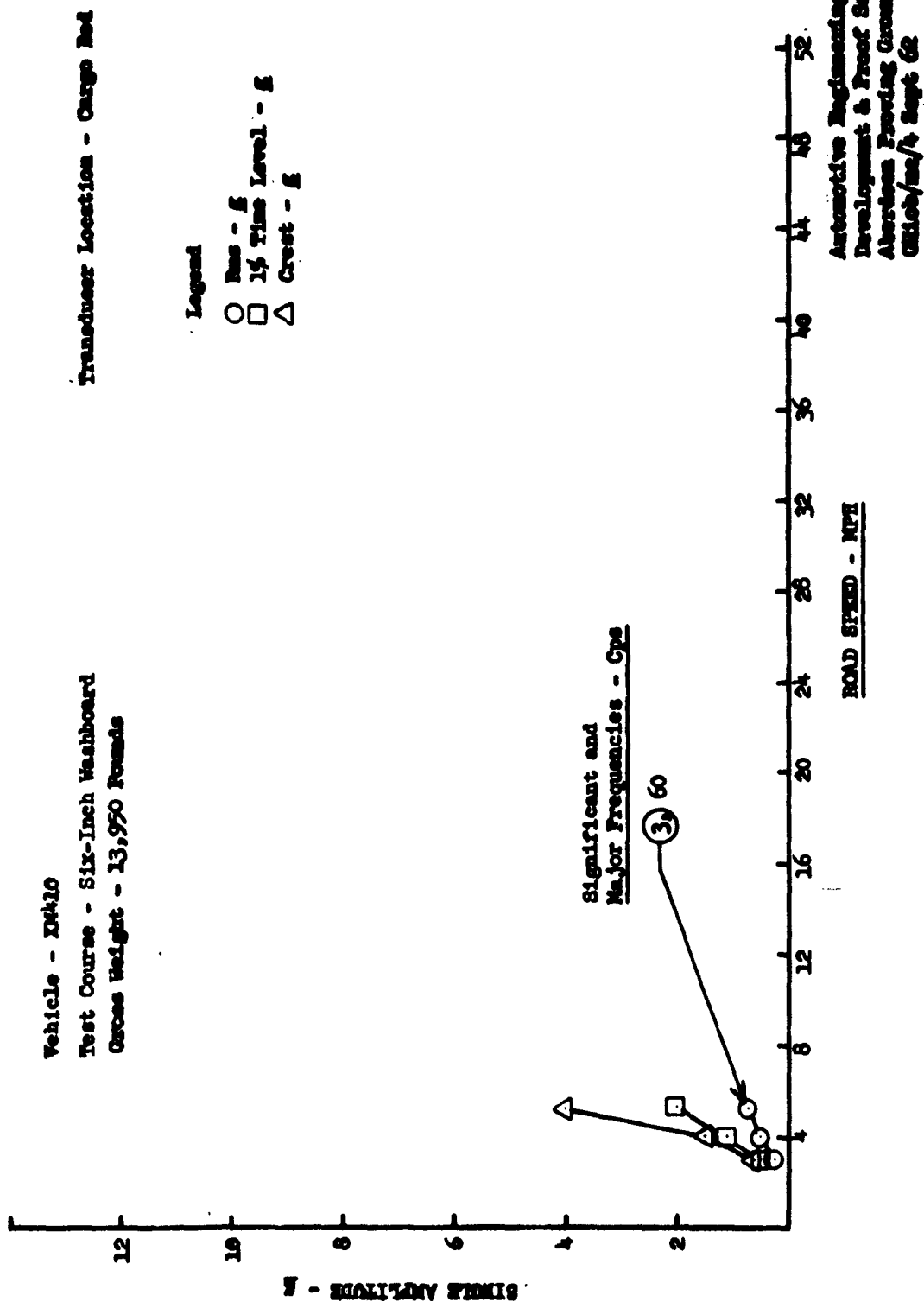
- Bus - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED



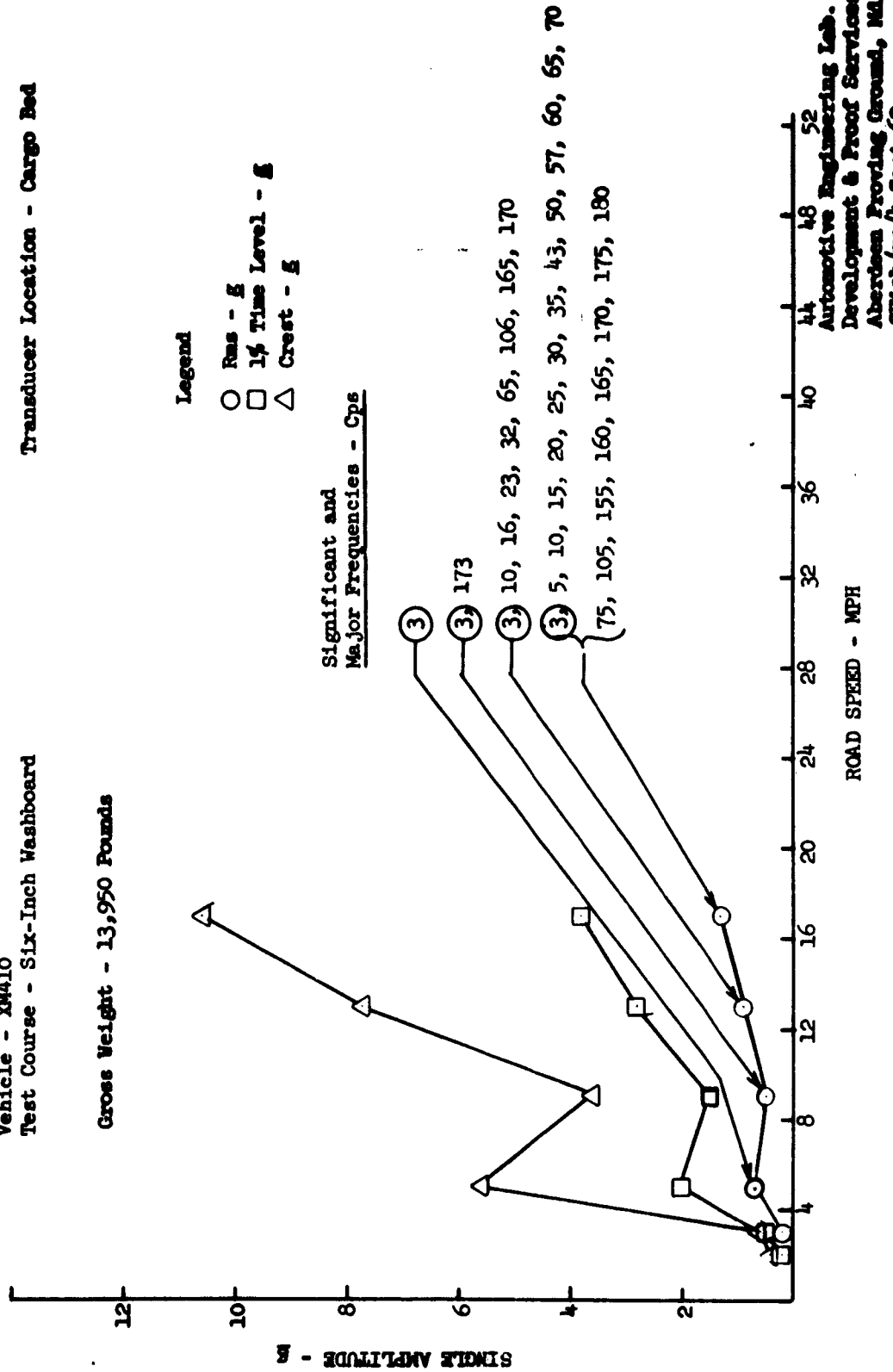
VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM410
Test Course - Six-Inch Washboard

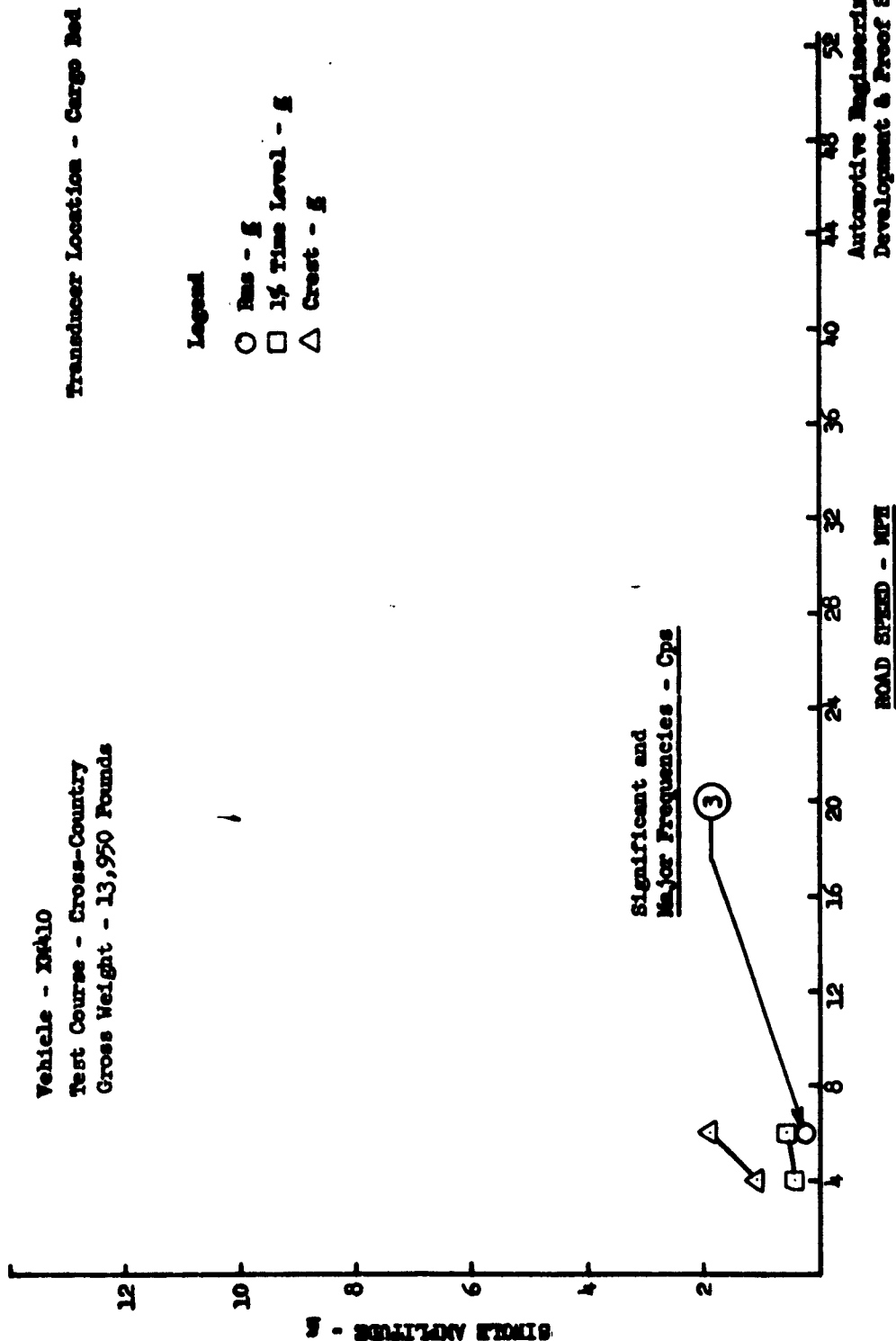
Transducer Location - Cargo Bed

Gross Weight - 13,950 Pounds



VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED



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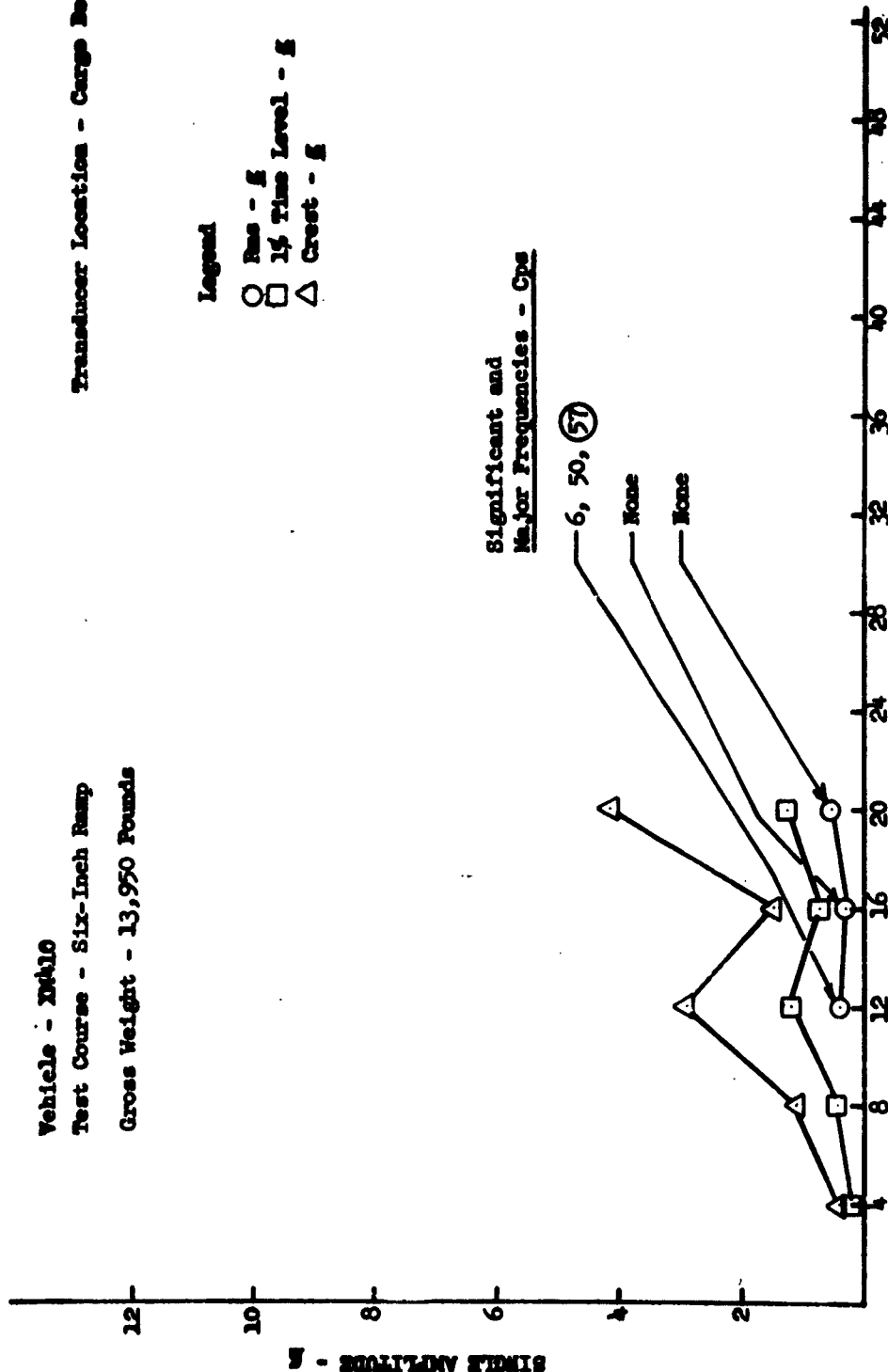
VIBRATION ENVIRONMENT (VERTICAL) AMPLITUDE VS ROAD SPEED

Vehicle - M4410
Test Course - Six-Inch Ramp
Gross Weight - 13,950 Pounds

Transducer Location - Cargo Bed

Legend

- Run - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Times Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$



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VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

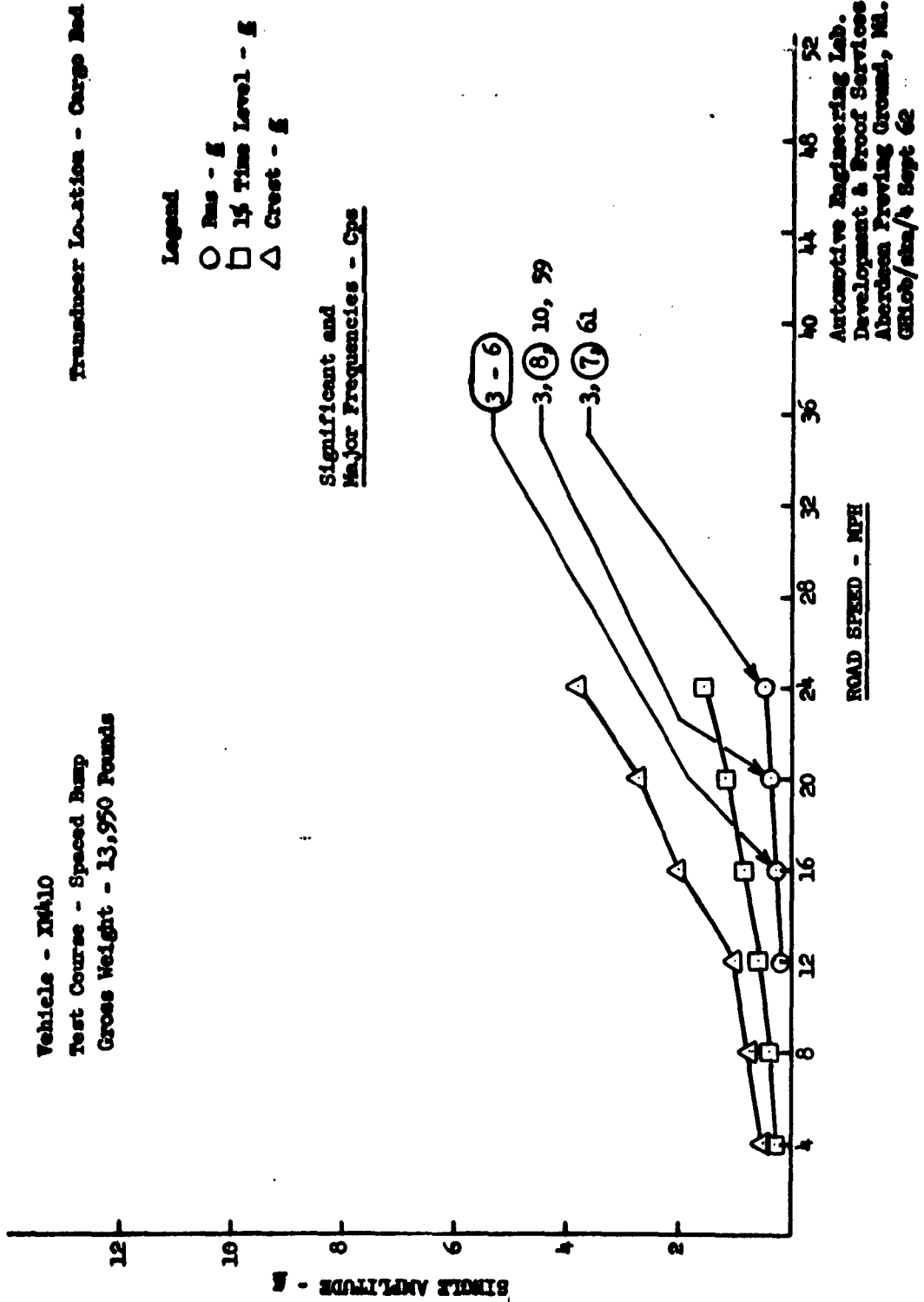
Vehicle - XM410
 Test Course - Spaced Bump
 Gross Weight - 13,950 Pounds

Transducer Location - Cargo Bed

Legend

- Bus - $\frac{1}{2}$
- 1 $\frac{1}{2}$ Time Level - $\frac{1}{2}$
- △ Crest - $\frac{1}{2}$

Significant and
 Major Frequencies - Cps



VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM125

Test Course - Belgian Block

Gross Vehicle Weight - 52,450 lbs

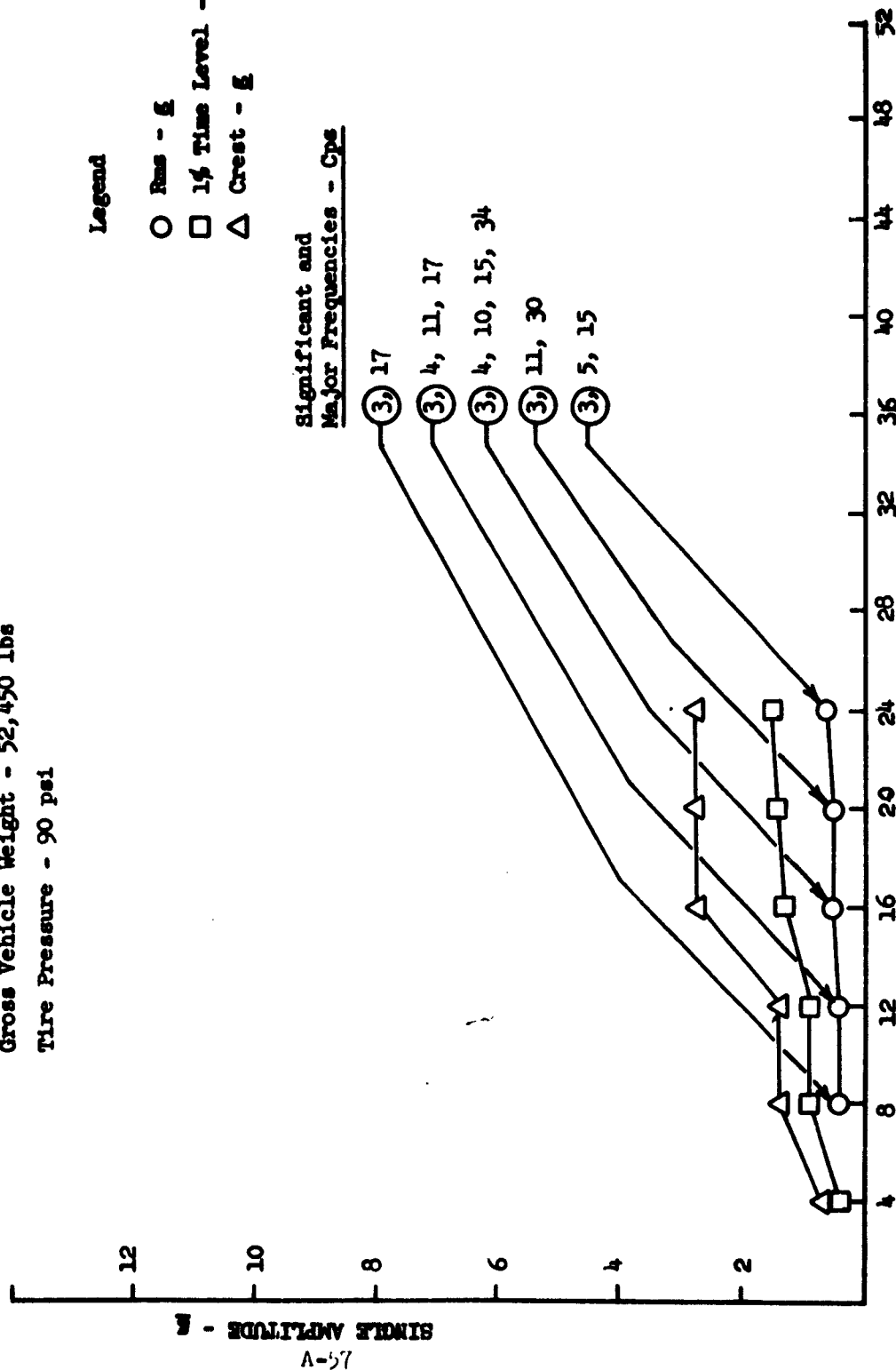
Tire Pressure - 90 psi

Transducer Location - Cargo Bed

Legend

- Rms - g
- 1/3 Time Level - g
- △ Crest - g

Significant and Major Frequencies - Cps



VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM125

Test Course - Spaced Bump

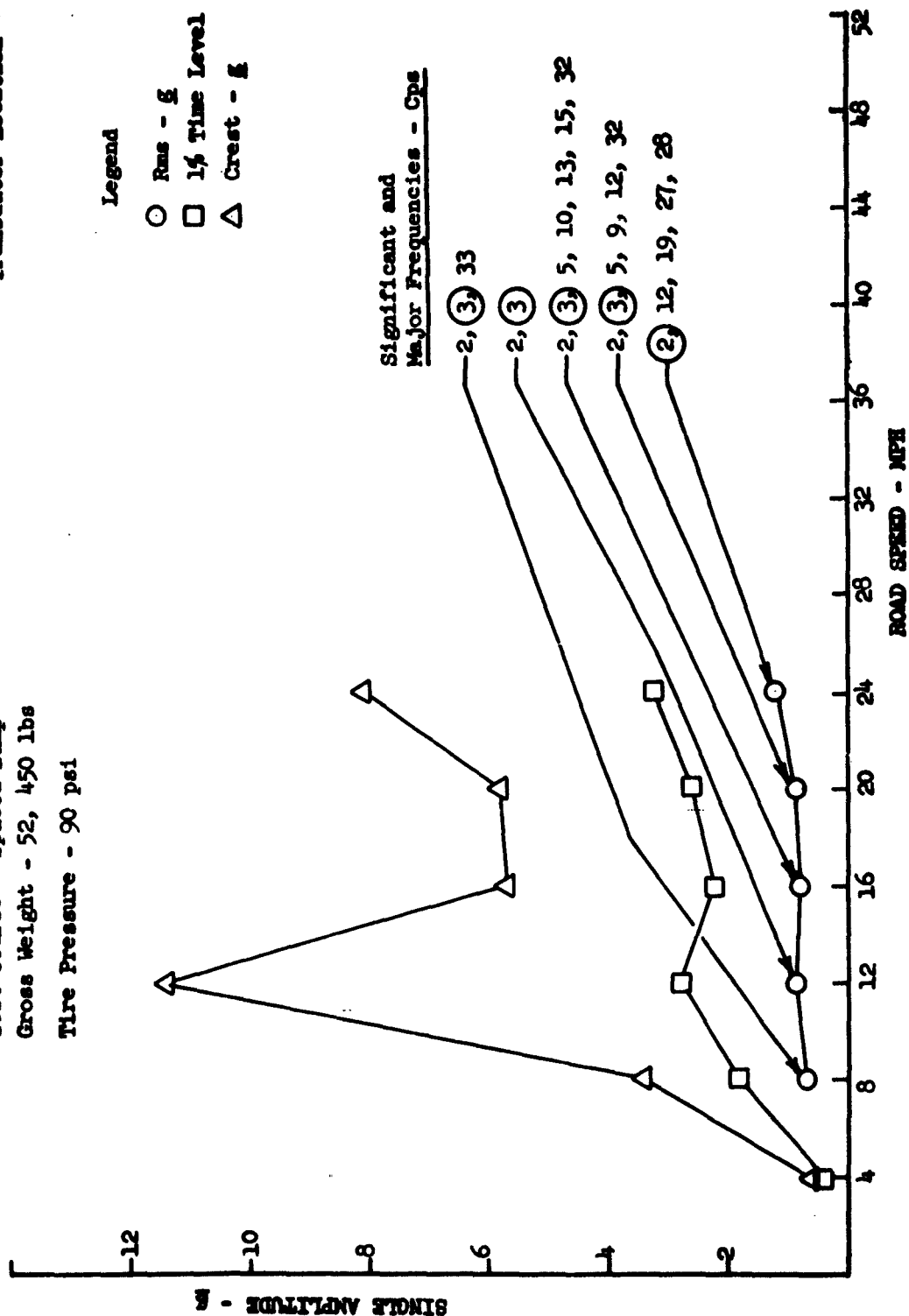
Gross Weight - 52, 450 lbs

Tire Pressure - 90 psi

Transducer Location - Cargo Bed

Legend

- Rms - g
- 1/3 Time Level - g
- △ Crest - g



VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM25

Test Course - Paved

Gross Weight - 52,450 lbs

Tire Pressure - 90 psi

Transducer Location - Cargo Bed

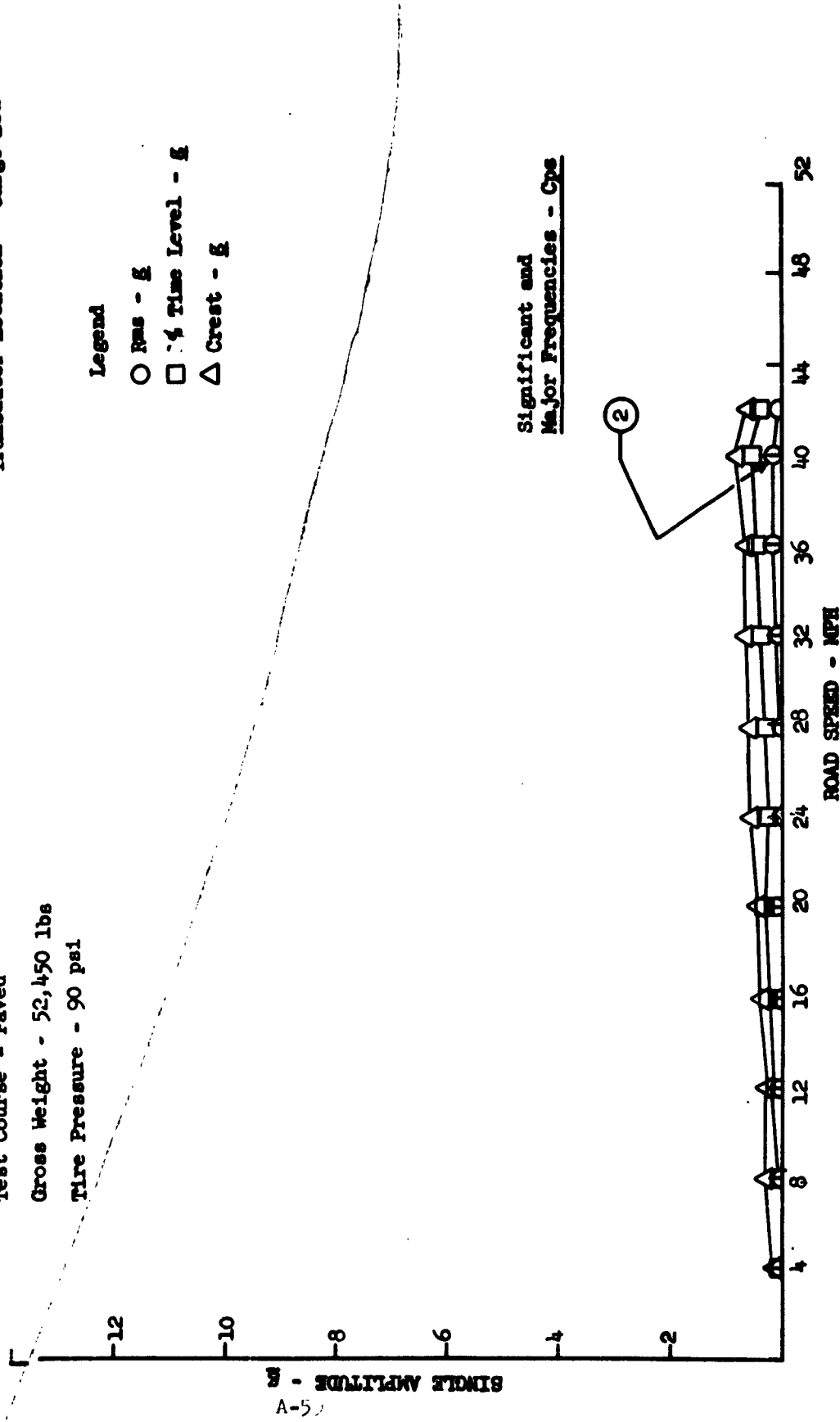
Legend

○ Rms - g

□ 1/4 Time Level - g

△ Crest - g

Significant and Major Frequencies - Cps



VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM125

Test Course - Six-Inch Ramp

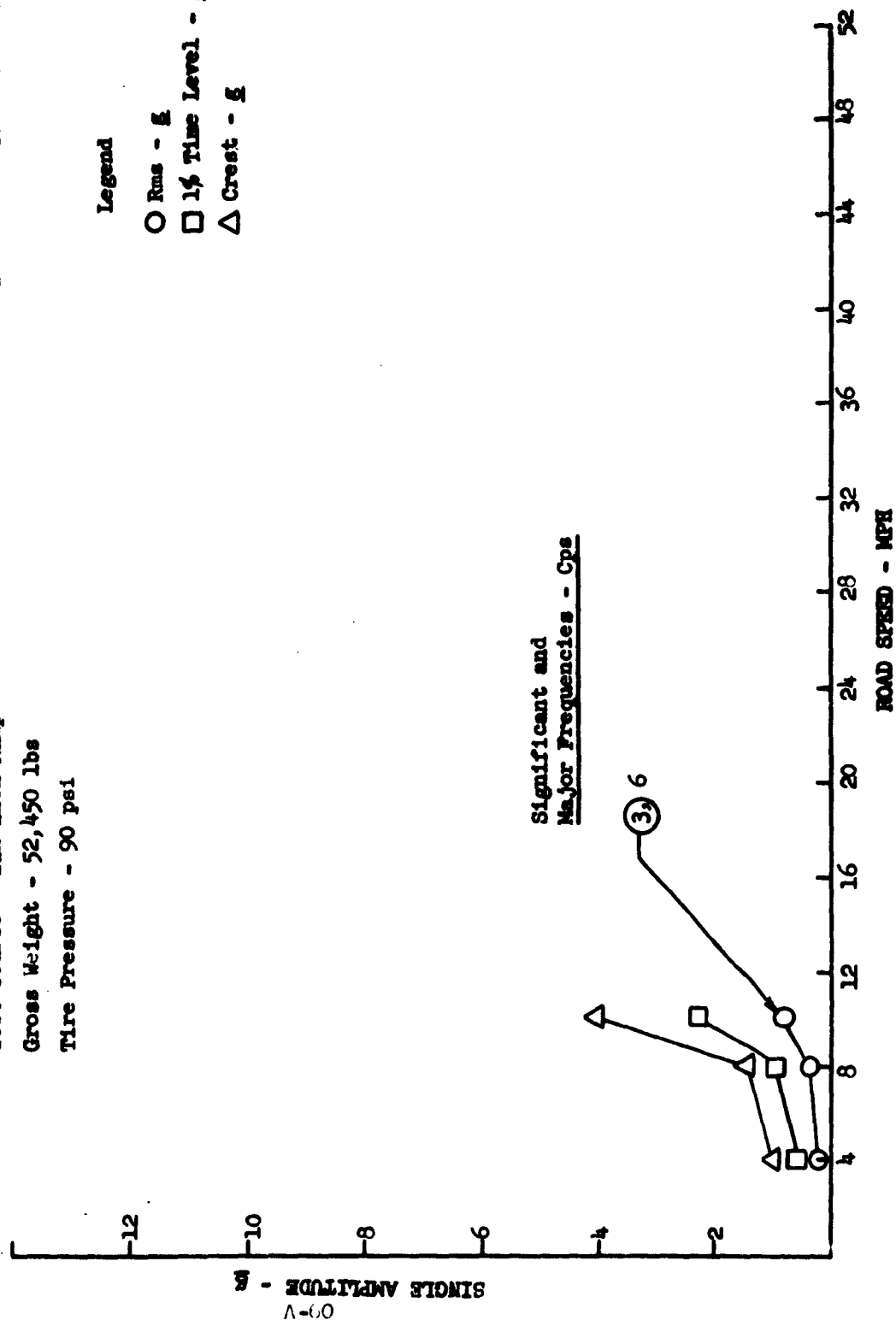
Gross Weight - 52,450 lbs

Tire Pressure - 90 psi

Transducer Location - Cargo Bed

Legend

- Rms - g
- 1/3 Time Level - g
- △ Crest - g



VIBRATION ENVIRONMENT (VERTICAL)

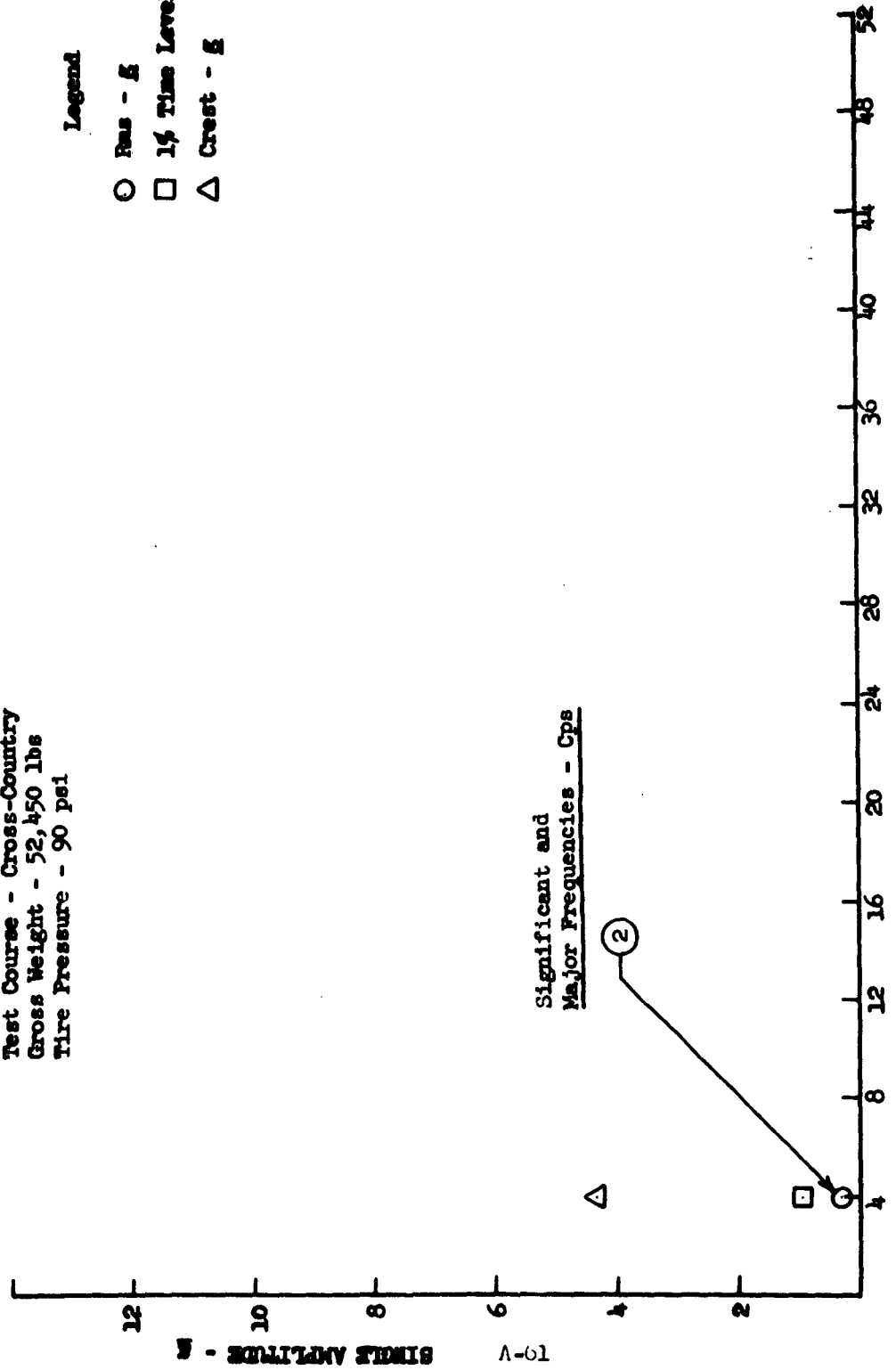
AMPLITUDE VS ROAD SPEED

Transducer Location - Cargo Bed

Vehicle - XM25
 Test Course - Cross-Country
 Gross Weight - 52,450 lbs
 Tire Pressure - 90 psi

Legend

- Bus - \bar{g}
- 1 $\frac{1}{2}$ Time Level - \bar{g}
- △ Crest - \bar{g}



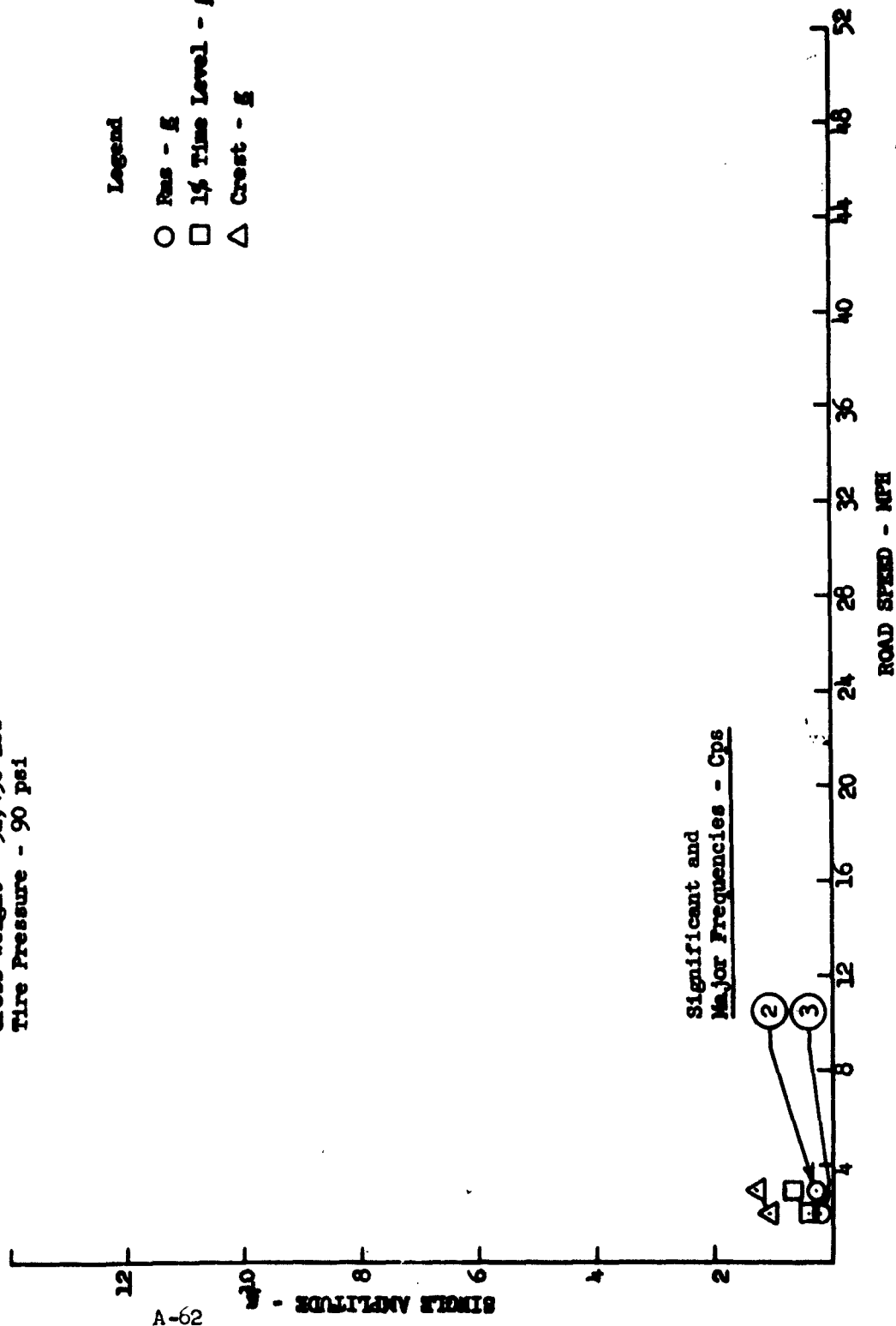
VIBRATION ENVIRONMENT (VERTICAL)

AMPLITUDE VS ROAD SPEED

Vehicle - XM25
 Test Course - Six-Inch Washboard
 Gross Weight - 52,450 lbs
 Tire Pressure - 90 psi

Transducer Location - Cargo Bed

- Legend
- Pass - \bar{g}
 - 1 $\frac{1}{2}$ Time Level - \bar{g}
 - △ Crest - \bar{g}



VIBRATION ENVIRONMENT (VERTICAL)

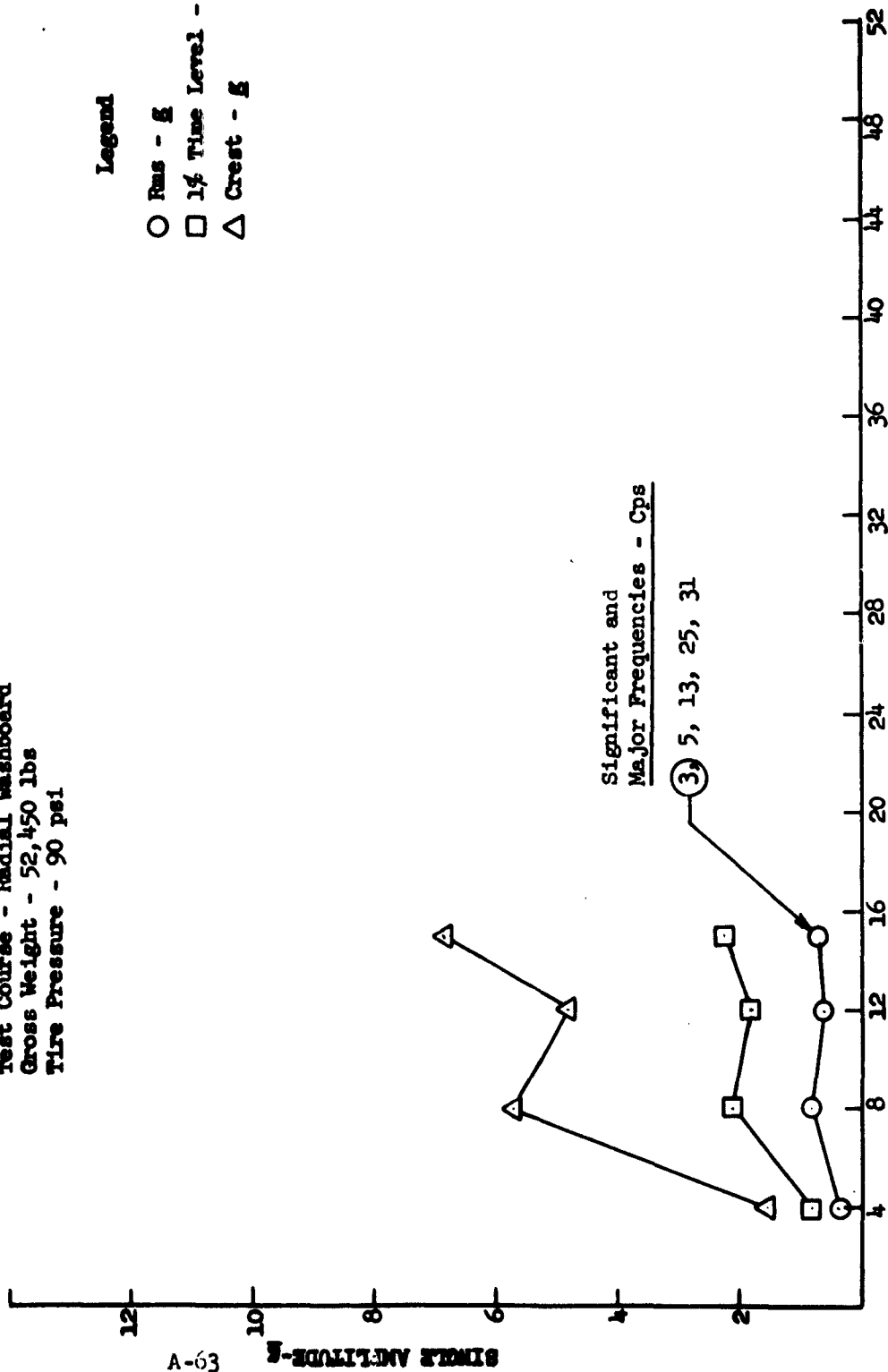
AMPLITUDE VS ROAD SPEED

Vehicle - XM125
 Test Course - Radial Washboard
 Gross Weight - 52,450 lbs
 Tire Pressure - 90 psi

Transducer Location - Cargo Bed

Legend

- Rms - \bar{g}
- $1\frac{1}{2}$ Time Level - \bar{g}
- △ Crest - \bar{g}



APPENDIX B

The Vibration Spectrum

Each data channel was analyzed spectrally. The mode chosen for this analysis was (power) spectral density (i.e., in terms of g^2/cps) since this weights the major frequencies. Examples of spectral analysis for individual course and speed conditions are shown on pages B-2 and B-3 for a wheeled and track-laying vehicle, respectively. Calculations of rms acceleration for the full spectrum were made for about 10% of the analyses made and compared with the rms acceleration estimated from the amplitude-distribution analysis. Agreement between the two methods was extremely good as would normally be expected.

To combine these individual spectral analyses into a composite description, significant amplitudes were extracted and plotted for each vehicle on pages B-4 through B-12. In preparing these plots, any band response (usually narrow) of 2.5 cps or more width was determined and plotted as a point at the appropriate (center) frequency for the band.

Individual analyses for each vehicle, channel, course, and speed condition are on file in the Automotive Engineering Laboratory.

For all spectral analysis covered by this report, the smoothing (integrating) time in real time was equal to the sample length in real time.

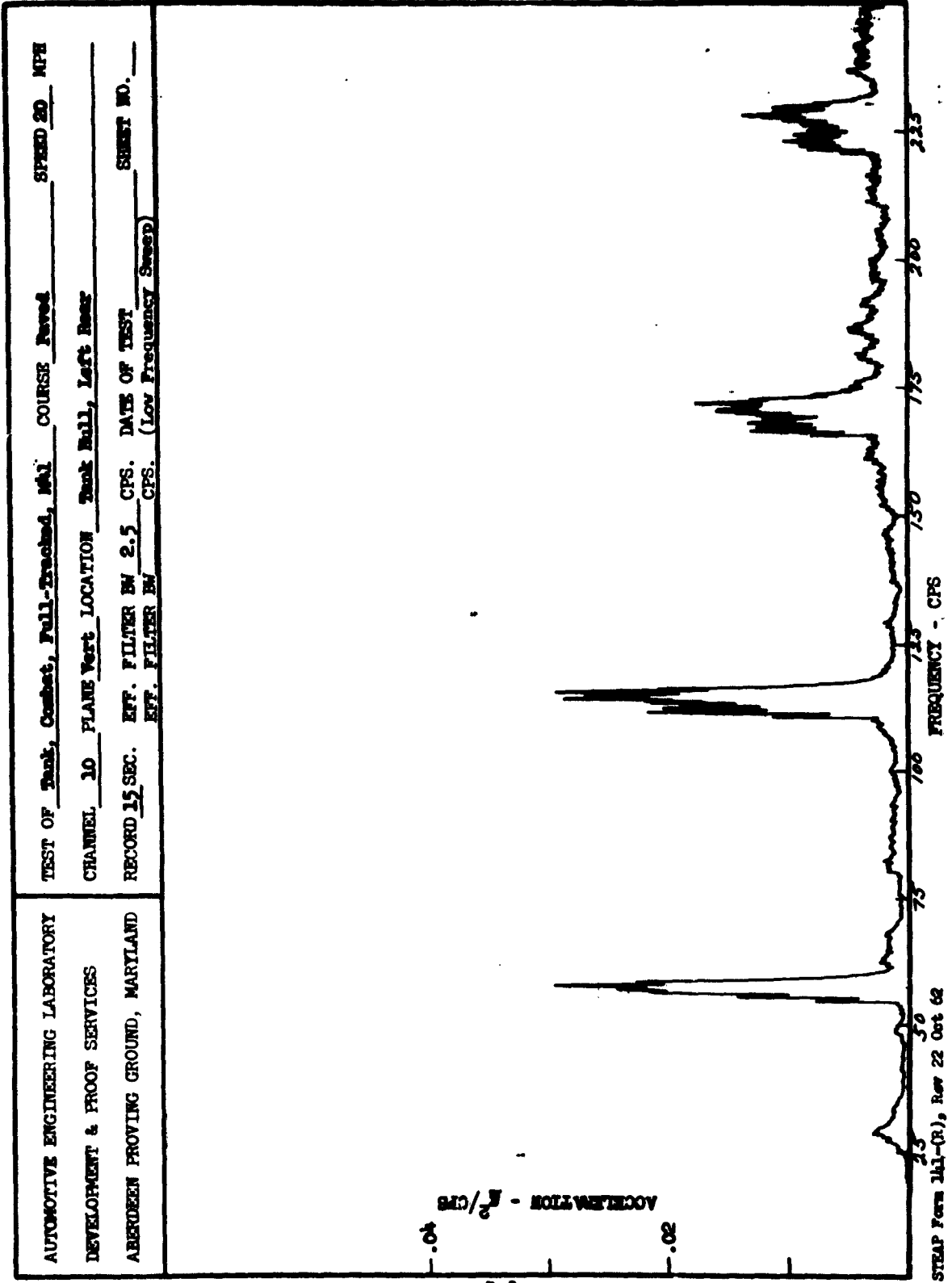
AUTOMOTIVE ENGINEERING LABORATORY
DEVELOPMENT & PROOF SERVICES
ABERDEEN PROVING GROUND, MARYLAND

TEST OF Truck, Cargo, 2-1/2 Ton, 6x6, M35 COURSE 2nd Wheelboard SPEED 6 MPH
CHANNEL 10 PLANE Vert LOCATION Left Rear of Cargo Bed
RECORD 15 SEC. EFF. FILTER BW 2.5 CPS. DATE OF TEST _____ SHEET NO. _____
EFF. FILTER BW _____ CPS. (Low Frequency Sweep)

AMPLITUDE - g/cps
B-2
0.20
0.15
0.10
0.05



STAP Form 141-1(R), Rev 22 Oct 62

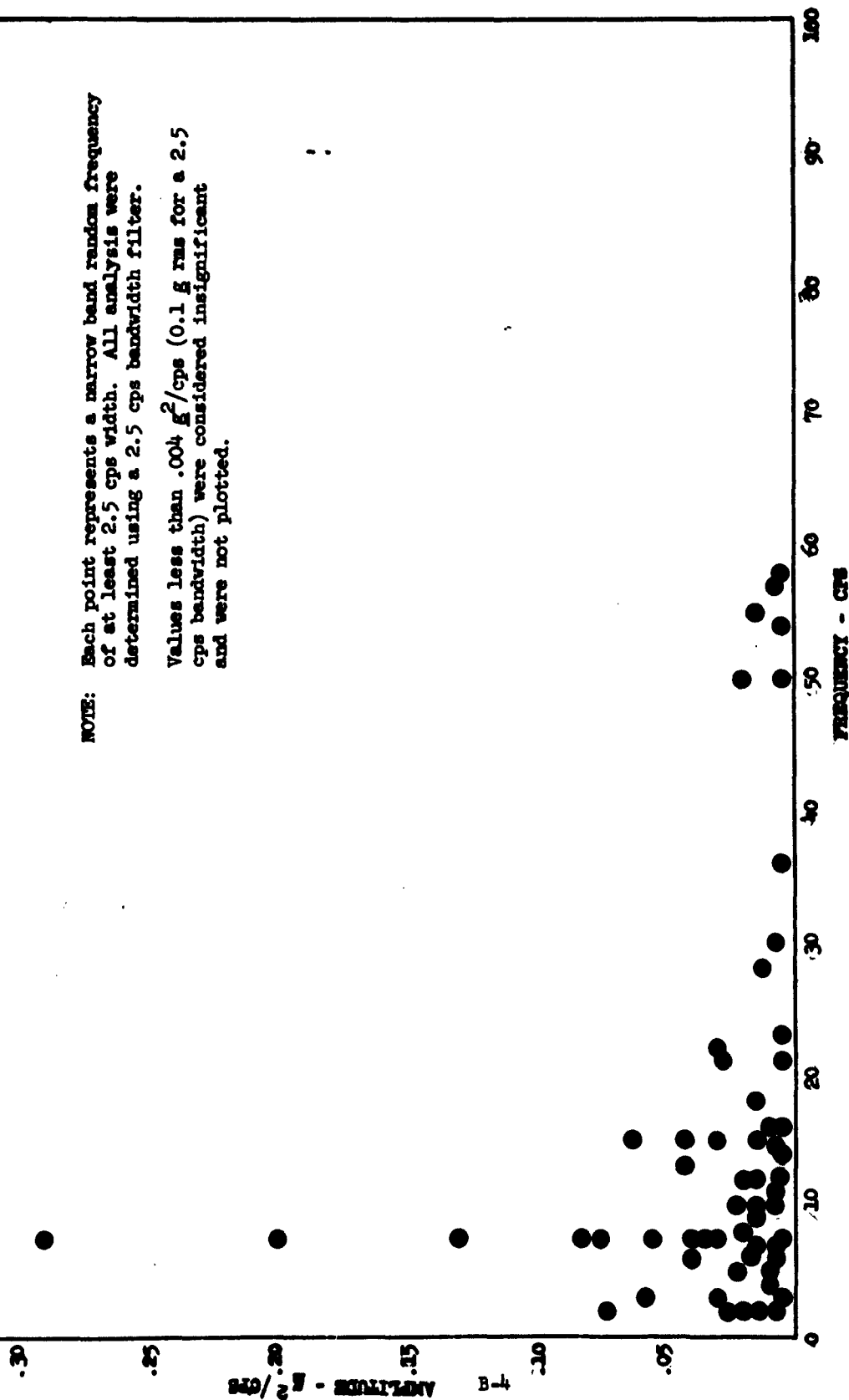


TRUCK, CARGO, 3/4 TON, K14, M37

**A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON CARGO BED
REGARDLESS OF TEST COURSE OR ROAD SPEED**

NOTE: Each point represents a narrow band random frequency of at least 2.5 cps width. All analysis were determined using a 2.5 cps bandwidth filter.

Values less than $.004 \text{ g}^2/\text{cps}$ (0.1 g rms for a 2.5 cps bandwidth) were considered insignificant and were not plotted.

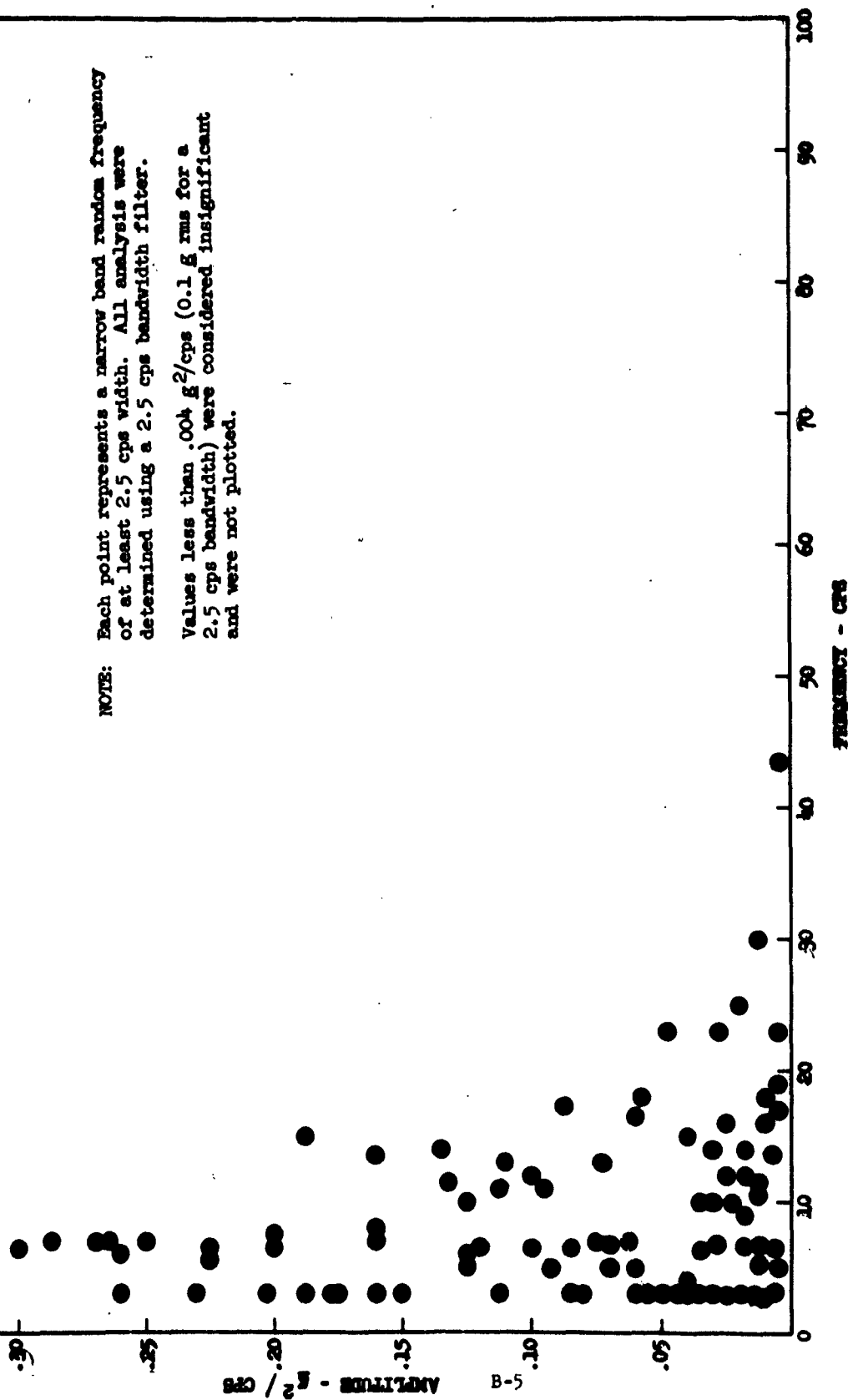


TRUCK, CARGO, 2-1/2 TON, 6X6, M32

A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON CARGO BED
REGARDLESS OF TEST COURSE OR ROAD SPEED

NOTE: Each point represents a narrow band random frequency
of at least 2.5 cps width. All analysis were
determined using a 2.5 cps bandwidth filter.

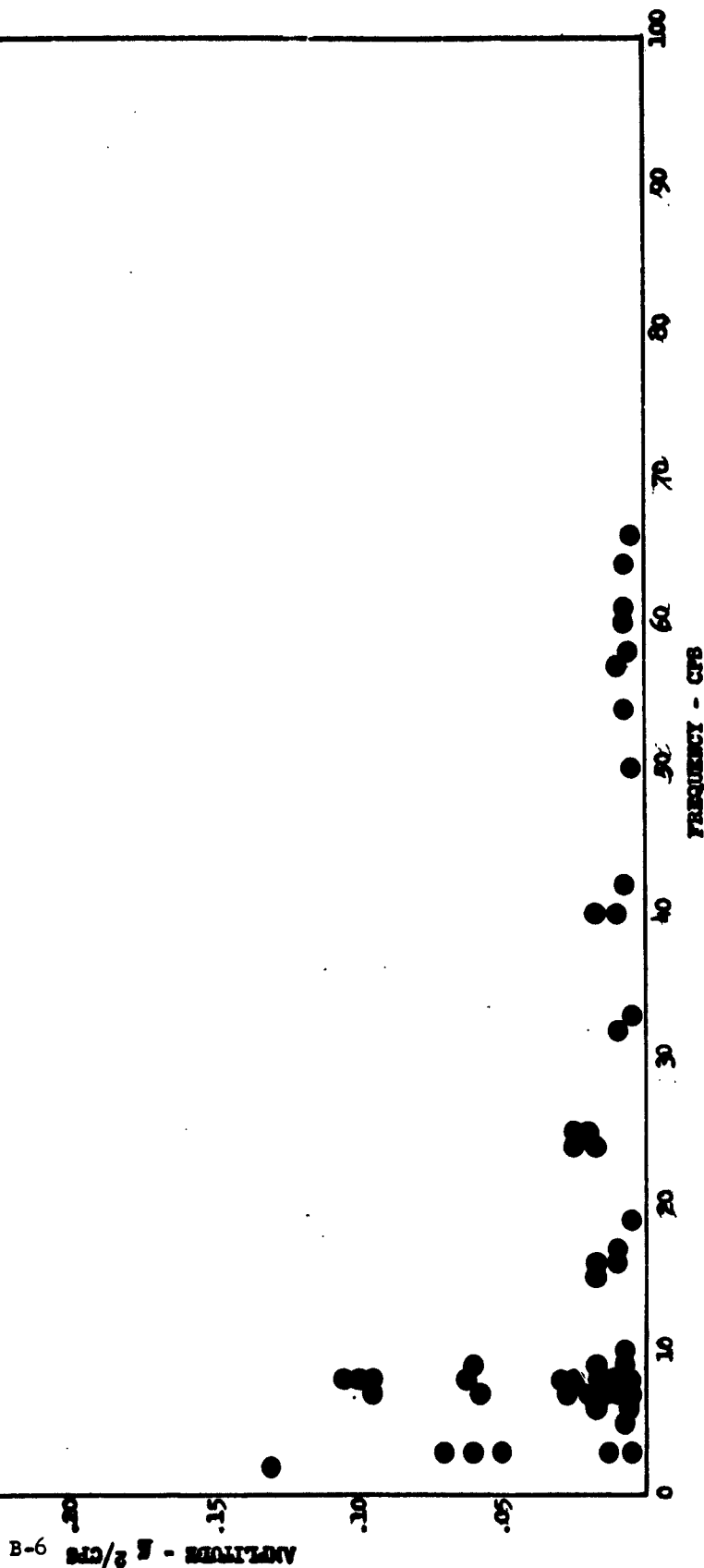
Values less than .004 g^2/cps (0.1 g rms for a
2.5 cps bandwidth) were considered insignificant
and were not plotted.



TRUCK, CARGO, 2-1/2 TON, 2x8, 14x10
A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON CARGO BED
REGARDLESS OF TEST COURSE OR ROAD SPEED

NOTE: Each point represents a narrow band random frequency of at least 2.5 cps width. All analysis were determined using a 2.5 cps bandwidth filter.

Values less than .004 g²/cps (0.1 g rms for a 2.5 cps bandwidth) were considered insignificant and were not plotted.

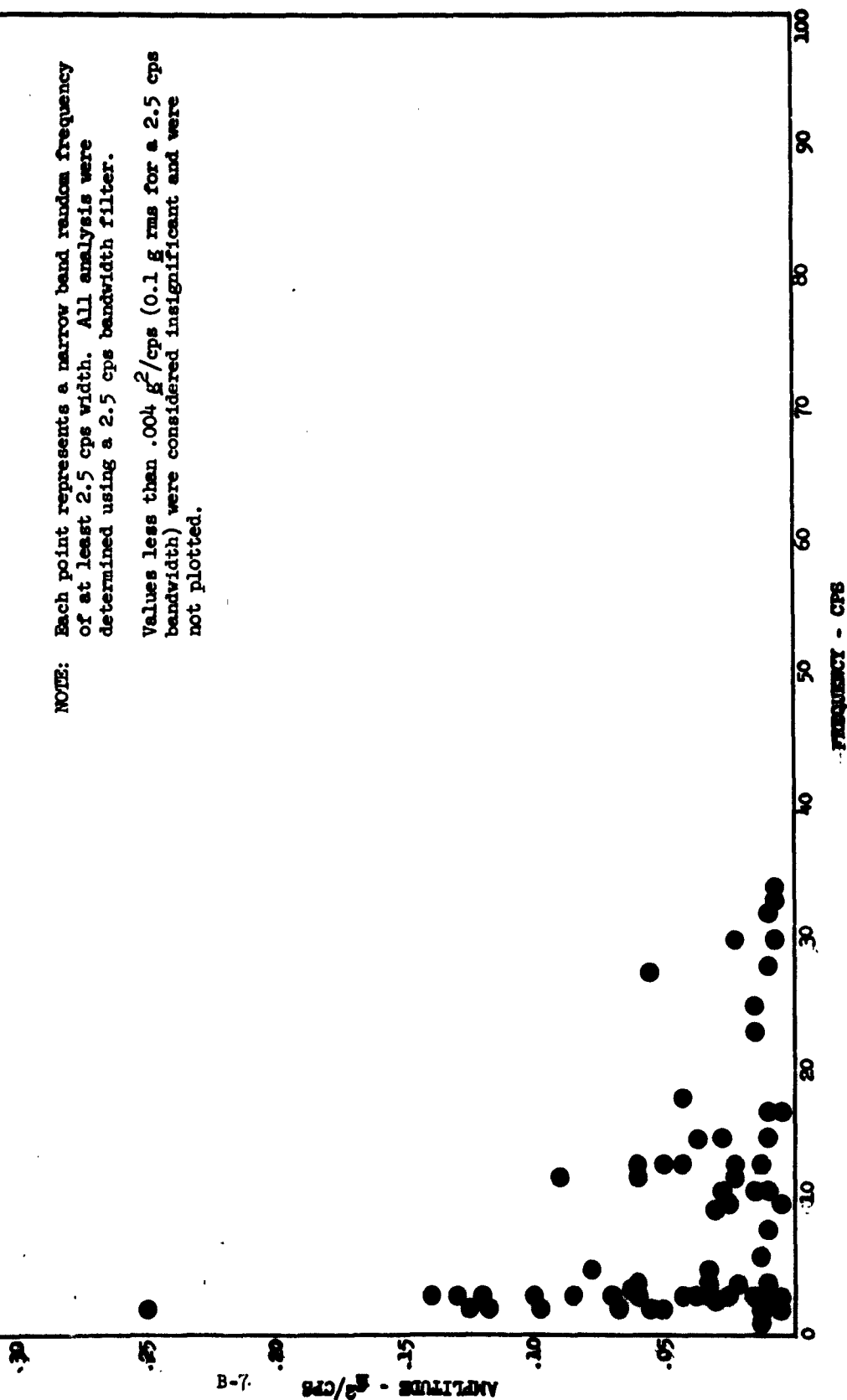


TRUCK, CARGO, 10 TON, 6X6, M25

A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON CARGO BED
REGARDLESS OF TEST COURSE OR ROAD SPEED

NOTE: Each point represents a narrow band random frequency of at least 2.5 cps width. All analysis were determined using a 2.5 cps bandwidth filter.

Values less than .004 g^2/cps (0.1 g rms for a 2.5 cps bandwidth) were considered insignificant and were not plotted.



CARRIAGE, GUN MOWER, M56

A COMPARISON OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON VEHICLE HILL
REGARDLESS OF TEST COURSE OR ROAD SPEED

.30

.25

B-3

.20

AMPLITUDE - $\frac{G}{\sqrt{H}}$ - SELECTION

.10

.05

0

NOTE: Each point represents a narrow band random frequency of at least 2.5 cps width. All analysis were determined using a 2.5 cps bandwidth filter.

Values less than .004g2/cps (0.1 g rms for a 2.5 cps bandwidth) were considered insignificant and were not plotted.

FREQUENCY - CPS

200

180

160

140

120

100

80

60

40

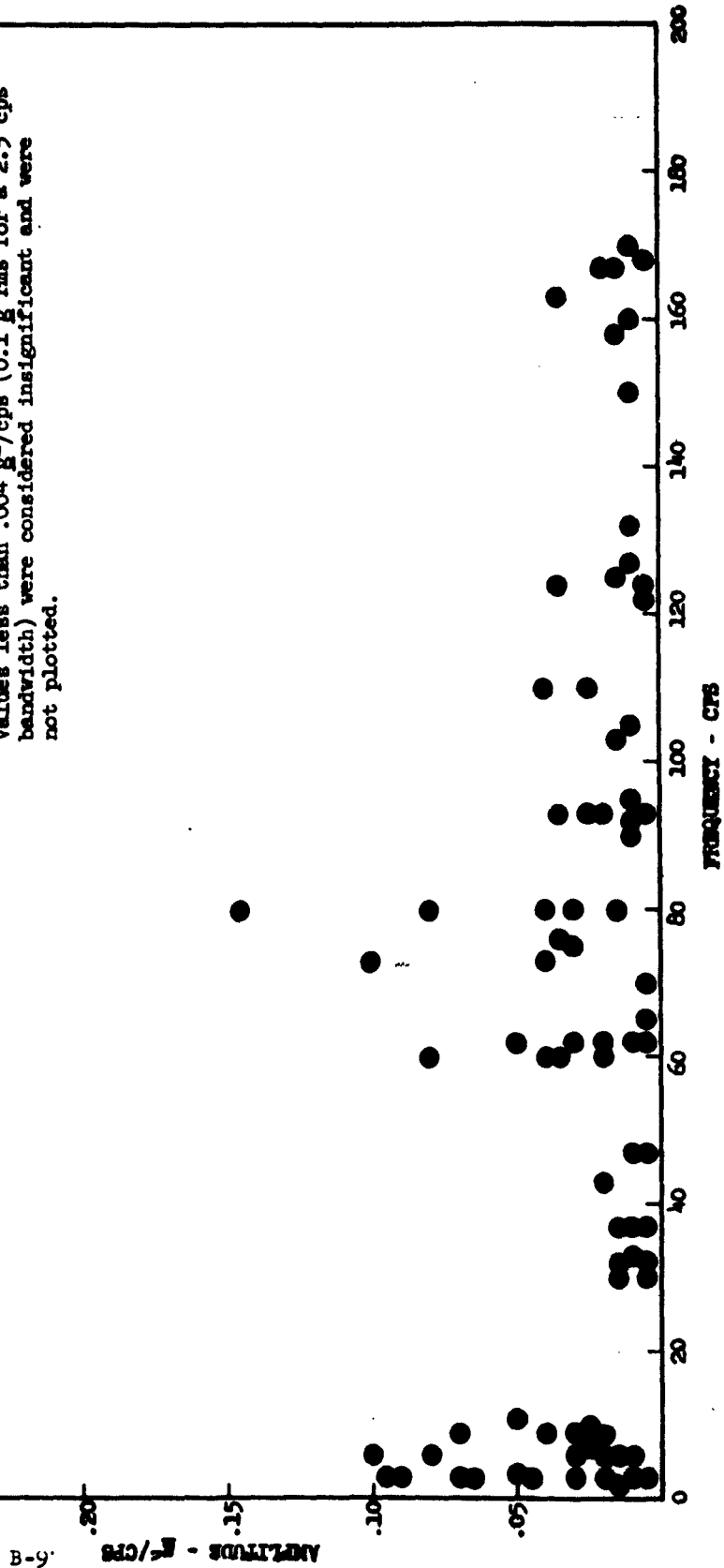
20

CARRIER, ARMORED, PERSONNEL, M113

A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON VEHICLE HULL
REGARDLESS OF TEST COURSE OR ROAD SPEED

NOTE: Each point represents a narrow band random frequency
of at least 2.5 cps width. All analysis were determined
using a 2.5 cps bandwidth filter.

Values less than .004 g²/cps (0.1 g rms for a 2.5 cps
bandwidth) were considered insignificant and were
not plotted.



CARRIER, PERCOWELL, TL16

**A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON VEHICLE HULL
REGARDLESS OF TEST COURSE OR ROAD SPEED**

NOTE: Each point represents a narrow band random frequency
of at least 2.5 cps width. All analysis were
determined using a 2.5 cps bandwidth filter.

Values less than $.004 \text{ g}^2/\text{cps}$ (0.1 g rms for a
2.5 cps bandwidth) were considered insignificant
and were not plotted.

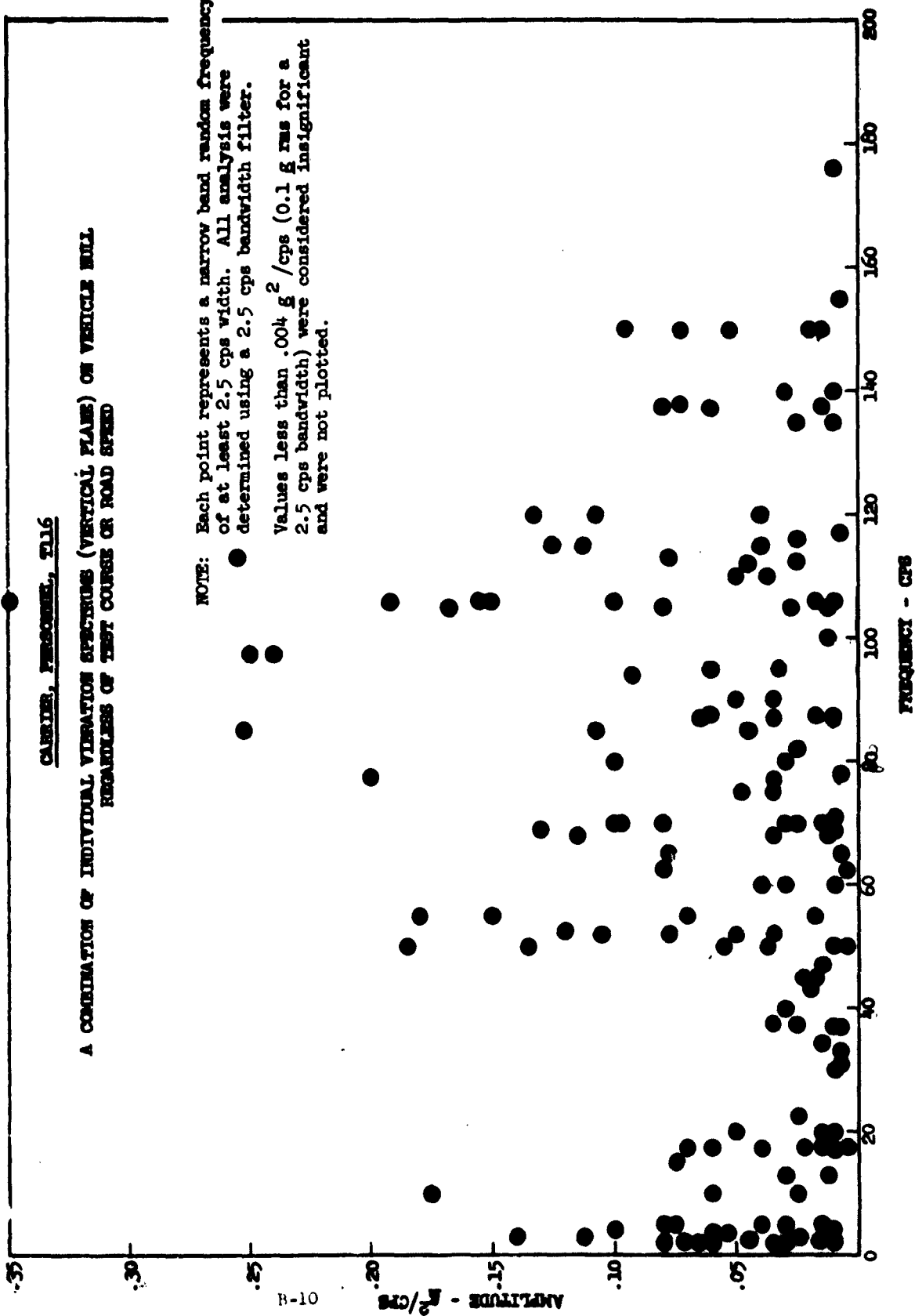
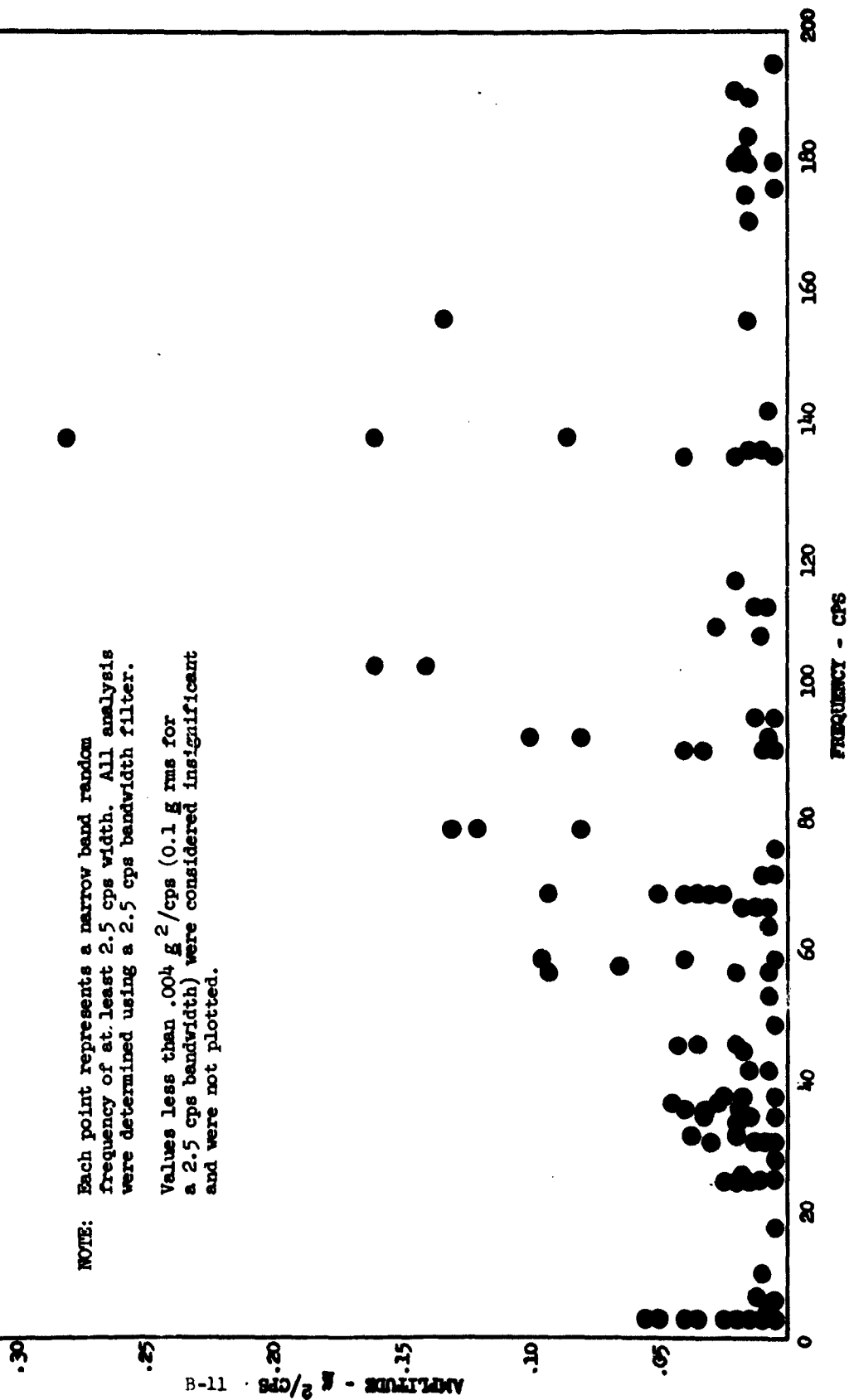


TABLE 20 M4 GUN, M41

**A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON VEHICLE HULL
REGARDLESS OF TEST COURSE OR ROAD SPEED**

NOTE: Each point represents a narrow band random frequency of at least 2.5 cps width. All analysis were determined using a 2.5 cps bandwidth filter.

Values less than .004 g²/cps (0.1 g rms for a 2.5 cps bandwidth) were considered insignificant and were not plotted.



TANK, MAIN BATTLE, 105 MM GUN, M60

A COMBINATION OF INDIVIDUAL VIBRATION SPECTRUMS (VERTICAL PLANE) ON VEHICLE HULL
REGARDLESS OF TEST COURSE OR ROAD SPEED

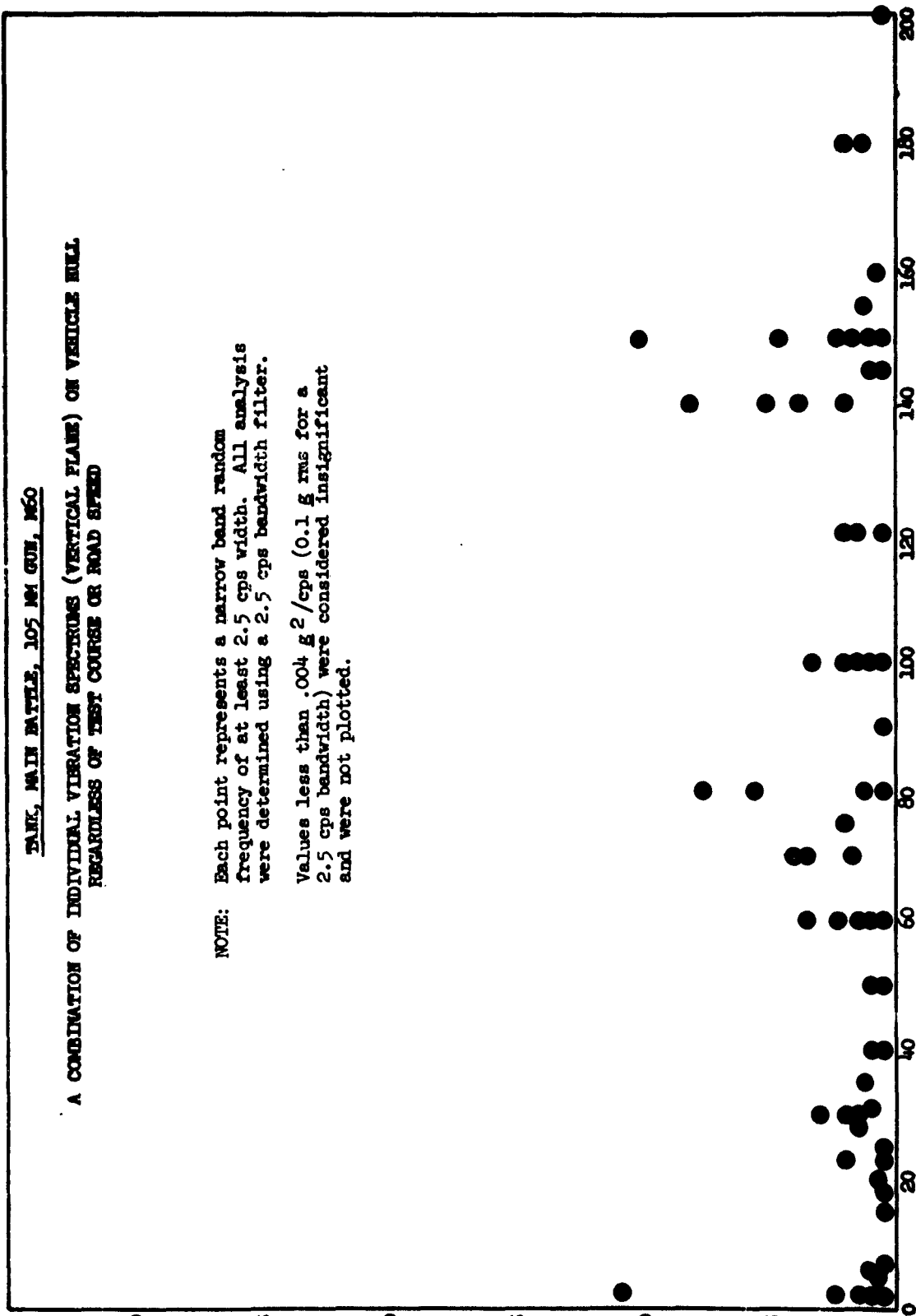
NOTE: Each point represents a narrow band random frequency of at least 2.5 cps width. All analysis were determined using a 2.5 cps bandwidth filter.

Values less than .004 g^2/cps (0.1 g rms for a 2.5 cps bandwidth) were considered insignificant and were not plotted.

B-12

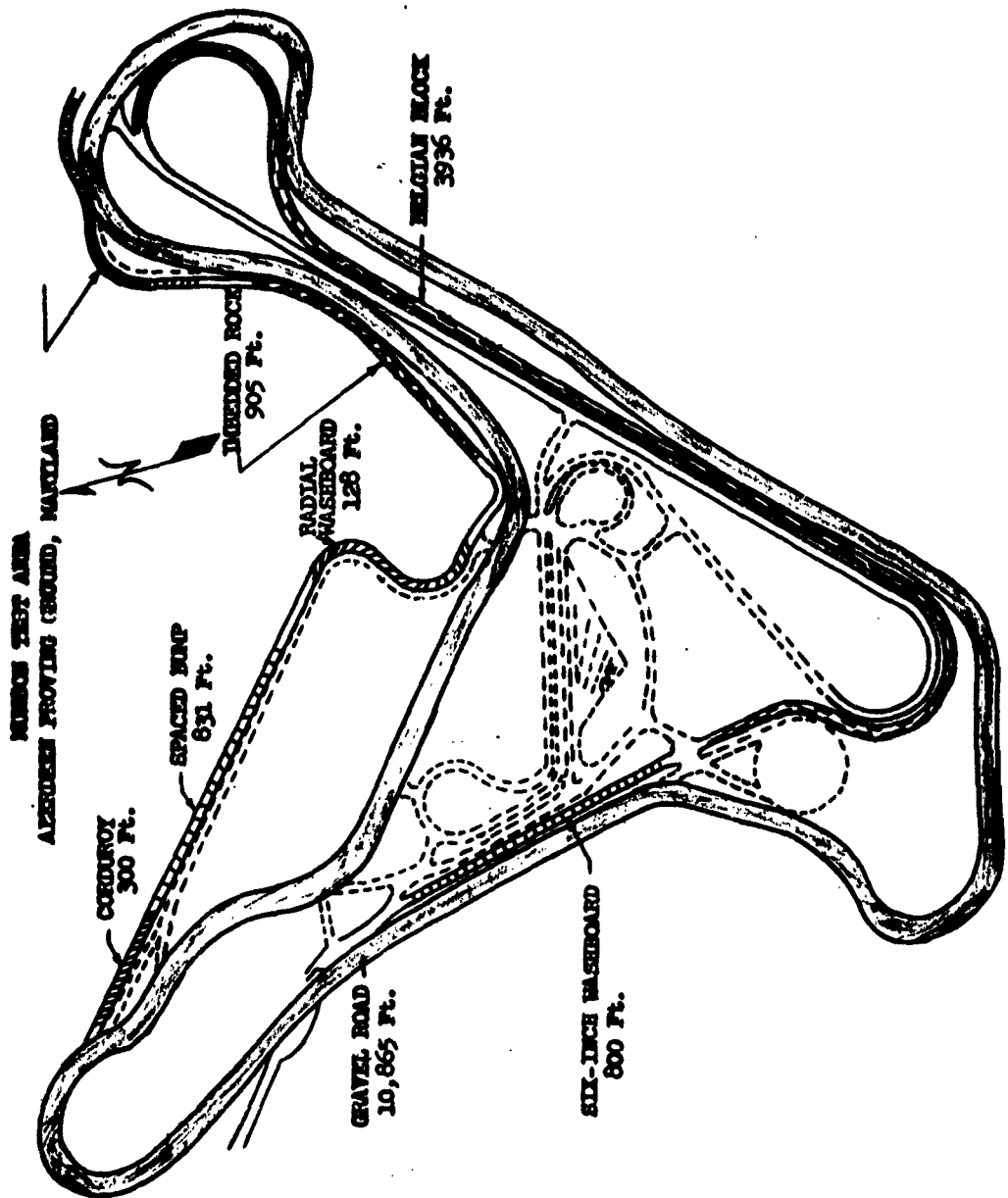
AMPLITUDE - g^2/cps

FREQUENCY - CPS

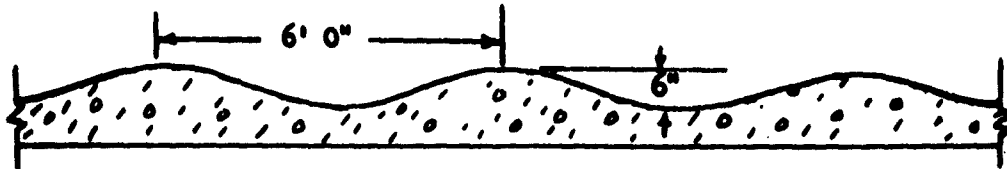


APPENDIX C

Course Profiles and Instrumentation Diagrams

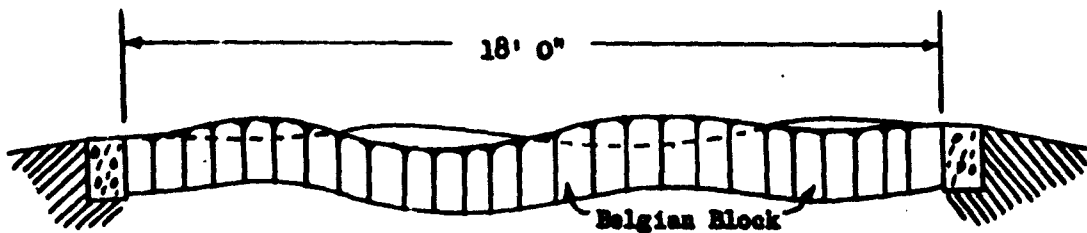


SIX-INCH WASHBOARD COURSE



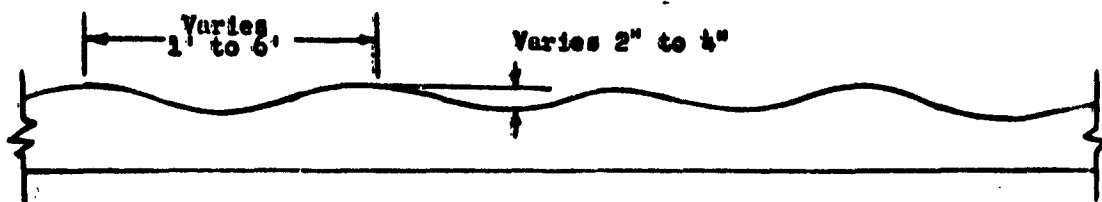
The profile approaches a sine wave with a double amplitude of six inches and a complete cycle occurring every six feet for a distance of 600 feet. The course surface is concrete.

BELGIAN BLOCK COURSE



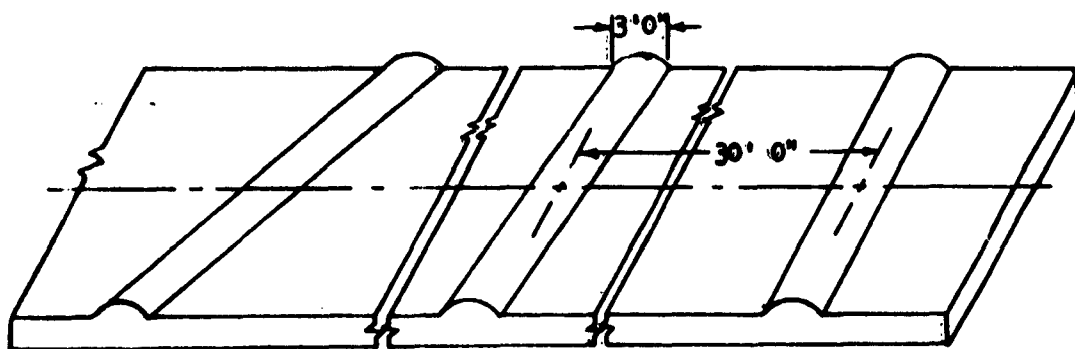
This course is a cobblestone road which provides an irregular and bumpy surface. The individual cobblestones average approximately five inches in width. The course irregularities, which not only vary along the length (3936 feet) of the course but also across its width, have crests of about three inches. The crests are such that a vehicle traveling over them is subjected to both pitching and rolling motions.

RADIAL WASHBOARD COURSE

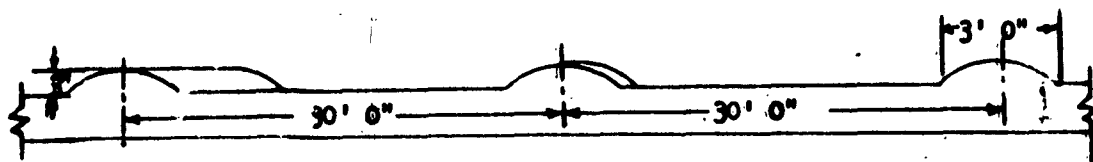


Two 90 degrees radial turns make up the Radial Washboard Course along with symmetrical bumps which vary from two to four inches in height and from one to six feet from crest to crest. The course is 128 feet long and 20 feet wide.

SPACED BUMP COURSE



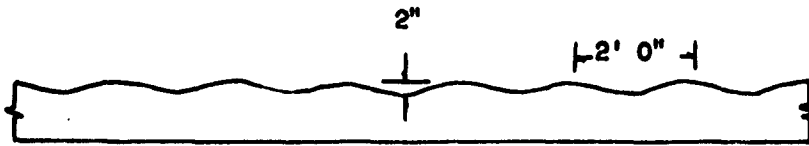
ISOMETRIC VIEW



LONGITUDINAL SECTION

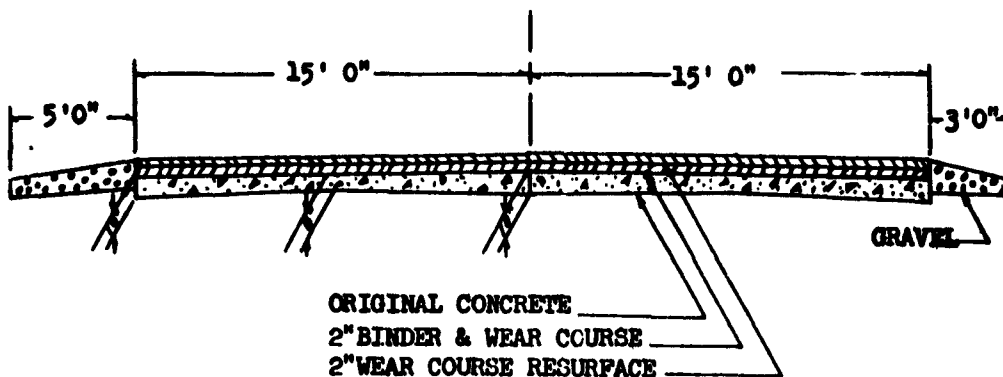
This course consists of a series of rounded bumps three inches high by three feet wide spaced at intervals of 30 feet along the centerline of the course. The bumps make the following angles with respect to the centerline of the course: 90°, 90°, 67°, 52°, 90°, 90°, 113°, 128°, 90°, 90°, this sequence continues for a total of twenty six bumps or three cycles for a total of 831 feet.

TWO-INCH WASHBOARD COURSE



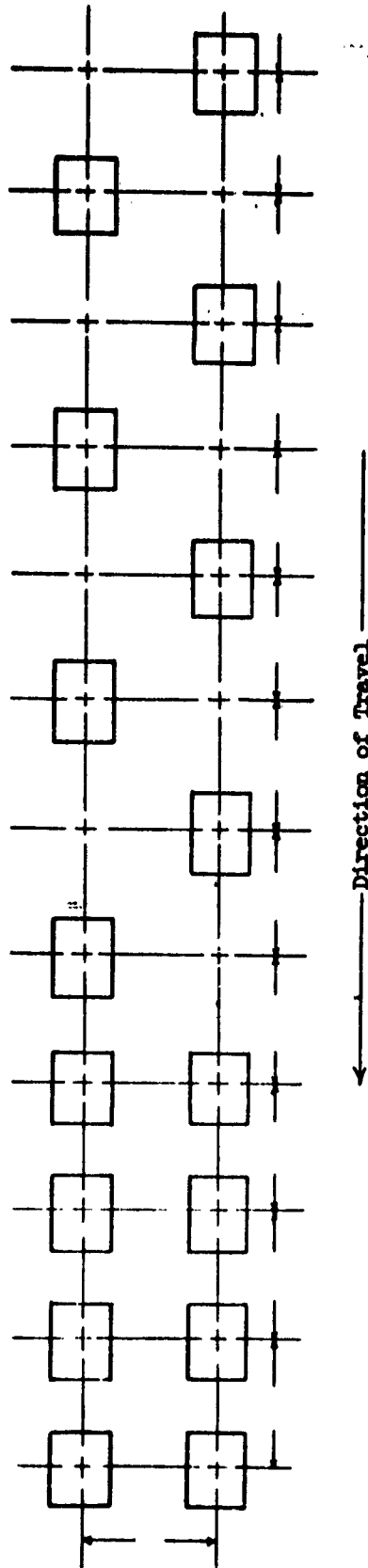
The profile approaches a sine wave with a double amplitude of two inches and a complete cycle occurring every two feet to a distance of approximately 300 feet. The course surface is concrete.

PERRYMAN STRAIGHTAWAY

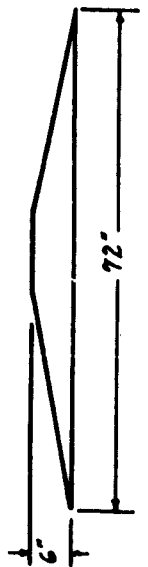
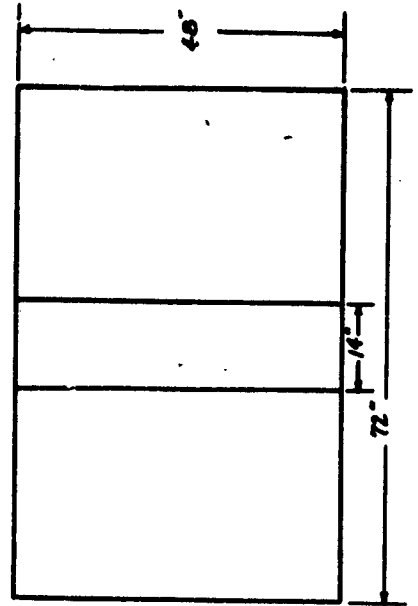


The paved straightaway is essentially a level road, three miles in length, with banked turn-around loops at each end. This course is used where high speed as well as tests requiring long periods of uninterrupted operation are desired.

DIAGRAM OF SPACING FOR RAMP COURSE
(Ramps Placed on Bituminous Concrete Surface)

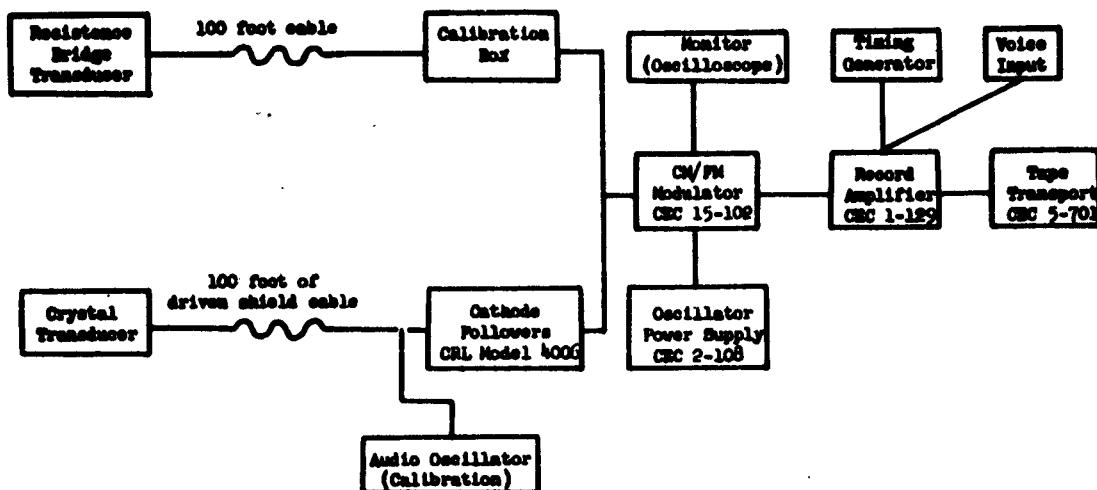


C-5



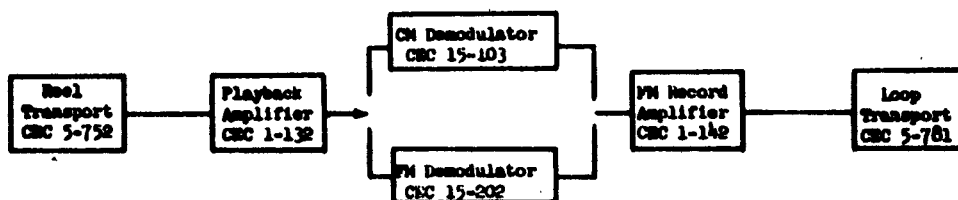
Ramp Dimensions

BLOCK DIAGRAM OF FIELD RECORDING INSTRUMENTATION

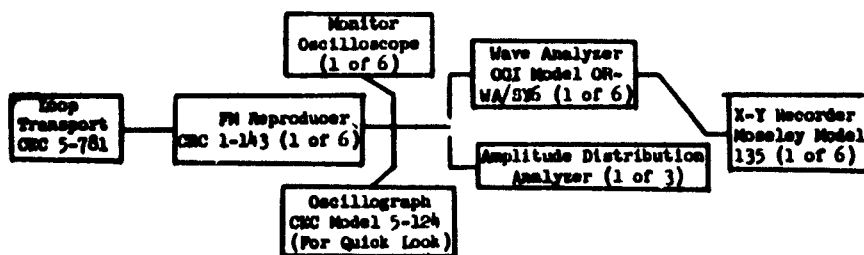


BLOCK DIAGRAM OF LABORATORY INSTRUMENTATION

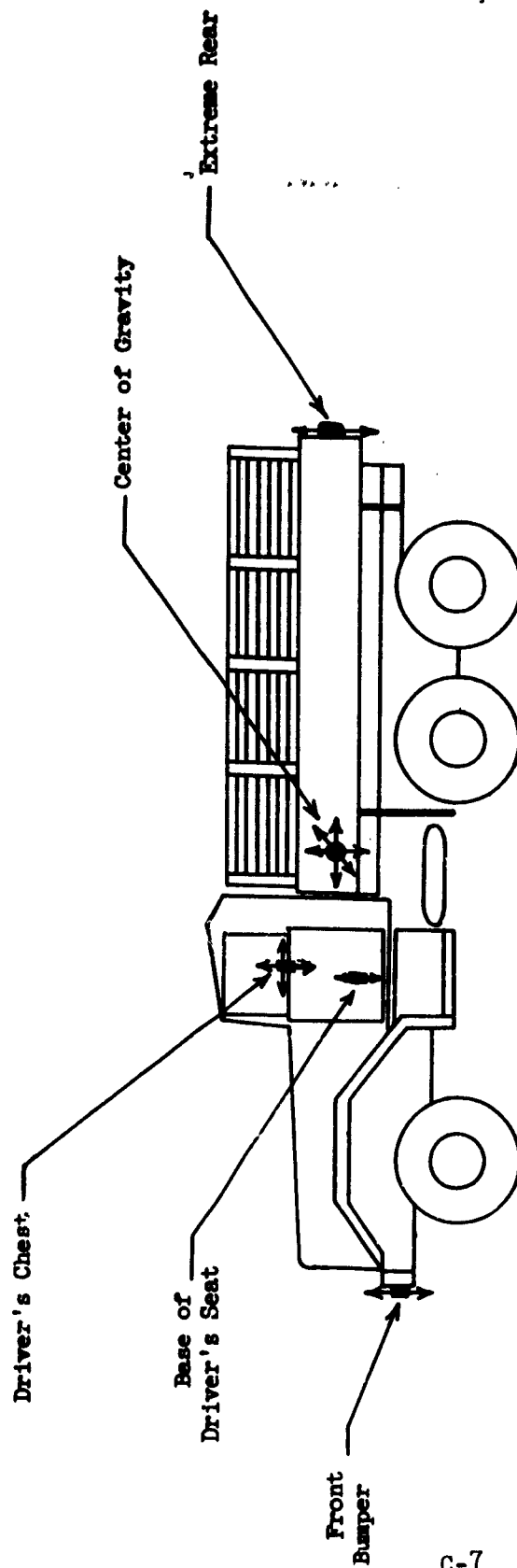
REEL TO LOOP TRANSFER



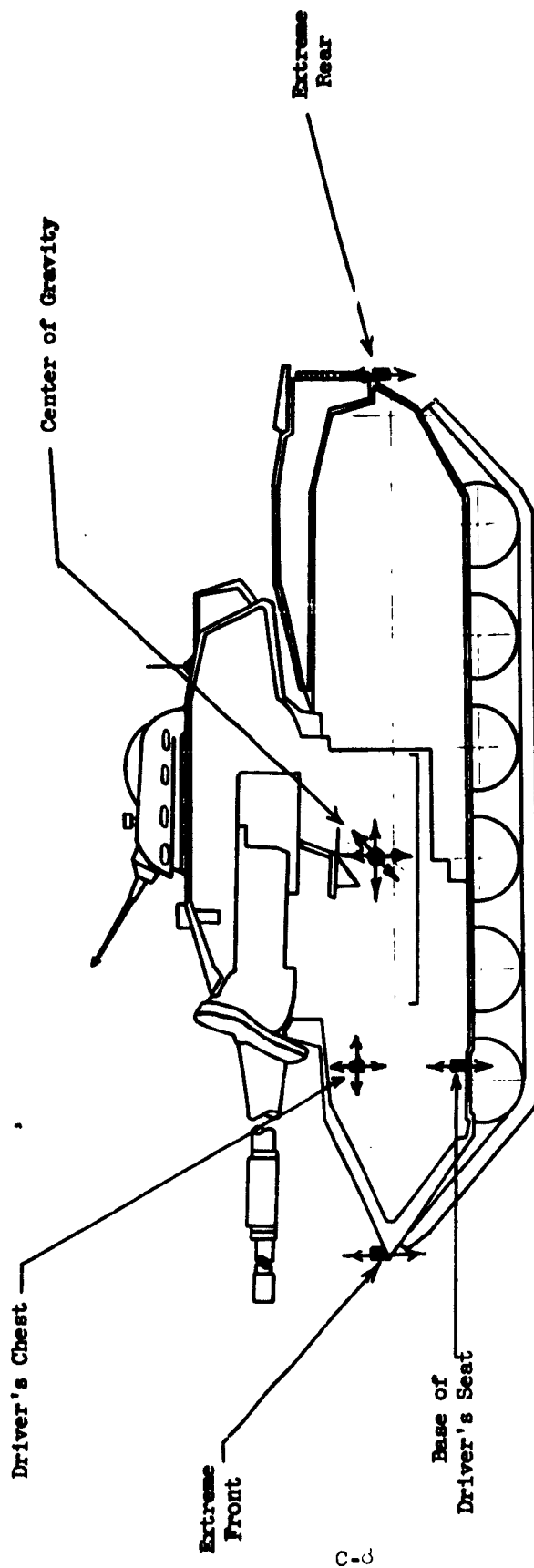
LOOP ANALYSIS



CEC - Consolidated Electrodynamics Corporation
 OGI - Ortholog Division - Gulton Industries
 CRL - Columbia Research Laboratories



Typical Transducer Locations for Wheeled Vehicle



Typical Transducer Locations for a Track Laying Vehicle

APPENDIX D

Report No. DPS-657

Development and Proof Services

AUTOMOTIVE ENGINEERING LABORATORIES

REPORT ON

**A STUDY ESTABLISHING METHODOLOGY
DESCRIBING THE AUTOMOTIVE VEHICULAR
VIBRATION AMPLITUDE ENVIRONMENT**

by

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R. W. JOHNSON

and

J. A. TOLEN

Report No. DPS-657

AUGUST 1962



*Aberdeen Proving Ground
Maryland*

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**A STUDY ESTABLISHING METHODOLOGY DESCRIBING THE
AUTOMOTIVE VEHICULAR VIBRATION
AMPLITUDE ENVIRONMENT**

Report No. DPS-657

Dates of Study: May to July 1962

ABSTRACT

Although a number of approaches have been made toward describing the automotive vehicular vibration amplitude environment, it is apparent that the entire area of effort lacks definitive terminology and that codification is required. Statistical considerations leading to a description of the probability-distribution function and the standard deviation are presented, and the non-Gaussian form of the probability distribution of the vibration environment is established. It is recommended that the method developed be used to describe the vibration amplitude environment of automotive vehicles.

CONTENTS

	<u>PAGE</u>
INTRODUCTION	3
APPROACH TO CODIFICATION	3
A PRIORI CONSIDERATIONS	4
PROBLEM DELINEATION	5
DATA ACQUISITION AND REDUCTION	6
DATA ANALYSIS AND RESULTS	9
ACCURACY OF RESULTS	19
LIMITATIONS OF ANALYSIS	20
APPLICATION OF METHOD	20
CONCLUSIONS	21
RECOMMENDATION	23
APPENDIX A: TEST COURSES	A-1
APPENDIX B: DISTRIBUTION	B-1

1. INTRODUCTION

The Automotive Laboratory, at customer request, performs tests relative to measuring the environment created by vehicles over specified test courses. Discussions with customer personnel reveal a complete lack of uniformity in data requirements. In some cases the customer reduces the data himself; in those cases his presentation usually produces an end result which is not in agreement or is not readily correlated with similar results or data previously obtained by the Automotive Laboratory. It is quite apparent that this entire area of effort lacks definitive terminology and codification is required.

2. APPROACH TO CODIFICATION

Two approaches to attempting codification exist. The first is to attempt to apply the existing body of knowledge on random processes to this field; this approach is short-lived. Although the existing body of knowledge is tremendous, one is faced immediately with trying to find a practical means of using this body of knowledge so that it has practical implications. The second approach is to attempt codification by hardware considerations, defining terminology in terms of hardware in such fashion that the definitions lead to numbers having immediate physical significance.

The general purpose of testing is to prove or improve reliability; thus failure criteria are involved in the design and testing. Both customer and test agency are concerned with failures and their cause. The automotive environment is characterized by its shock and vibration spectrum, thus failures due to shock and vibration appear to be a fruitful area in which to attempt codification. A shock and vibration environment induces two types of failures, the first due to fatigue, the second due to stress level. One would reasonably expect that fatigue failure would be associated with the vibration environment and ultimate stress induced failures due to shock. The first definition that must be established is that of shock as opposed to vibration; this definition must be compatible with the type of failures and with the automotive environment. Basing the definition on failure type would infer that shock differs from vibration in stress level induced in the hardware; this is not the case. A vehicle and its on-board gear form a complex vibratory system and, when in resonance with a course, induced forcing function can produce high stress levels on both the vehicle components and its on-board gear. Under the proper conditions, a vibratory environment can thus produce very high stress levels, yet this could not be defined as shock. A definition that appears to satisfy the failure criteria and still make sense when referred to the automotive environment is: "Shock response is a response of significant amplitude that occurs at a repetition rate lower than the lowest damped natural frequency of the vehicle or its on-board gear." The definition of "significant amplitude" will be discussed later. The remainder of the response after "shock" is stripped out will be defined as "vibration."

3. A PRIORI CONSIDERATIONS

The preceding definition of shock is basic to the statistical study that is the subject of this report. Since the definition is all important, other systems of analyzing the vehicular environment should be examined to determine the acceptability of the definition. A common means of dissecting vibration information is to record the phenomenon on magnetic tape and play the tape through a spectrum analyzer. The spectrum analyzer can be set to display the pertinent vibration information in several ways. The comments that follow concern the display of amplitude (rms, average, or peak) versus frequency.

The spectrum analyzer in essence is a device that passes the analog vibration information through a narrow filter; the output of the filter thus is quasisinusoidal to the extent that there exists in the original data information that will pass through the filter. Since the amplitude at the filter output is highly variable, an averaging circuit is provided to smooth the presentation. As a result, the amplitude-versus-frequency display provides average amplitude. Unfortunately, an average is meaningless, unless something is known of the distribution of the elements that have been averaged; this type of display thus, in itself, only indicates that there exists in the original data more, or less, analog information at one particular frequency setting of the filter than some other setting.

Consider now, the operation of a vehicle over a course, say a paved road, for a period of 60 seconds. Since each section of the paved road is reasonably like any other section of the road the vehicular environment should be a stationary process. Now, suppose we lay a single large timber across the course. What effect will the passage of the vehicle over this artificial bump have on the resulting record? Since such a "bump" occupies an insignificant percentage of the total time of passage of the vehicle over the course its contribution to the rms value of the amplitude would be insignificant. This single "bump" may, however, be an order of magnitude greater than any other peak on the record. For some types of on-board gear or vehicle, this single "bump" may be the only significant factor in the operation over the course.

Now, in considering such a situation, it becomes obvious that the introduction of this single bump changes the stationary random process to a nonstationary process. Were the 60-second record cut into smaller pieces the one piece containing the bump would be significantly different from the others. If the size of the bump were such as to produce an acceleration that was not statistically different from the peaks throughout the remainder of the record, then it would not substantially alter the stationary process, and could thus be treated statistically as part and parcel of the vibration environment. We thus find that shock should be differentiated from vibration only if the shock pulse is statistically different from the vibration environment.

Now consider what occurs if we attempt to analyze the 60-second run with a large single-shock pulse on a spectrum analyzer operating in the amplitude versus frequency mode. The 60-second run on magnetic tape is made into a loop and played into the spectrum analyzer. Each time the shock pulse is presented to the

analyzer, some energy will pass through the filter irrespective of the position of the filter-pass band in the spectrum. Since the magnitude of the shock pulse is large, the integrating or averaging time constant will not completely hide the phenomenon, and a series of spectral lines will be displayed. The envelope of these lines is a Fourier integral representation of the shock pulse. The extent to which the lines are apparent on the record is a function of the averaging time, the percentage of the total loop length occupied by the shock pulse as well as the amplitude of the shock pulse relative to the vibration environment. Here, again, is a manifestation that the shock pulse is statistically different from the vibration environment.

Returning now to the test course, if we place not one but many bumps on the test course, what can we expect? Assume for the moment we place so many bumps on the course that the "amplitude severity" now reflects primarily the presence of the bumps and these pale the vibration environment into insignificance. In this case, cutting the 60-second run into sections reveals that the process is once again stationary, but is now far more severe than in the preceding case. Here, the spectral lines on the spectrum analyzer blend into a homogeneous curve showing a broad display of low frequencies. Also, we find that this limiting case of the shock environment can be treated and discussed as a vibration environment. Thus, shock can be defined as being statistically and spectrally different from vibration and thus leads to the preceding definition.

4. PROBLEM DELINEATION

The preceding discussion provides the basis for framing the problem. "Is it possible through statistical considerations to provide a simple means of describing the automotive vehicular environment?" The definition of shock divides the environment into two parts; one part, the vibration environment is expected to be represented as a stationary process; the second part, shock is represented as a nonstationary process and thus cannot be described by statistical means. The immediate consideration is finding a means of describing the vibration environment. Since amplitude is the parameter of interest and, since the amplitude is a function of time, it appears the analysis must center about determining the probability of the amplitude exceeding specified values. The probability-distribution function of the amplitude in time is thus the immediate goal. Given the probability-distribution function and the standard deviation, the distribution of amplitude in time is completely described. The approach is as follows:

- a. Establish the stationarity of the phenomenon.
- b. Examine data to determine the form of the probability-density function.
- c. Establish a means for readily determining the probability-distribution function of a particular record, and a method for determining the standard deviation of the amplitude.

5. DATA ACQUISITION AND REDUCTION

The data were collected from Statham unbonded strain gage accelerometers, flat from 0 to 270 cps, with a damped natural frequency of 400 cps, range ± 25 g. These were located on the front and rear of the vehicles and oriented to measure acceleration in a vertical plane, and at the center of gravity of the vehicle in three mutually perpendicular planes (vertical, transverse, and longitudinal). The vehicles included in the program were:

- a. Carrier, personnel, full-tracked, armored, M113.
- b. Truck, cargo, 10-ton, 6x6, XM125.
- c. Truck, cargo, 2-1/2 ton, 8x8, XM410.
- d. Truck, cargo, 2-1/2 ton, 6x6, M35.
- e. Tank, combat, full-tracked, 105-mm gun, M60.

The output of the accelerometers was recorded on magnetic tape which had a frequency response of 0 to 600 cps. The vehicles were operated over the standard APG test courses; these courses are described in Appendix A of this report. The data are re-recorded from the original magnetic tape onto a loop of tape, the frequency response of the loop system is 0 to 625. The loop is then played into a statistical counter (frequency response 0.5 to 750 cps), the output of the statistical counter is the basis for the analysis that follows; complete understanding of the statistical counter is mandatory to proper understanding of the analysis.

The statistical counter is a device that measures and prints out the time that the amplitude exceeds prescribed reference levels. Data from the magnetic tape loop are fed into the counter, and, during each revolution of the loop, the counter integrates the time the amplitude exceeds a level. Nine positive and nine negative levels are scanned in this manner. Additionally, the analyzer prints out the total length of time represented by a loop. Dividing the total time into the time for each level thus produces the percentage of time the amplitude is in excess of the specified level. The percentage of time and the probability are identical, thus the statistical counter in essence describes the probability-distribution function. The data produced by the statistical counter can be plotted on probability paper and thus a means exists for rapidly collecting probability distributions. A typical record from the statistical counter is shown in Table I and a probability-distribution plot from this record is Figure 1.

The amplitude levels built into the statistical counter are 3 db apart. If a value of 1 is assigned to the 1st level, the amplitudes of the other levels can be described relative to the 1st level as follows:

$$L = 1 + \frac{20}{3} \log A$$

where A = amplitude relative to 1st level

L = Level (1 to 9).

Table 1. Typical Record from Statistical Counter

Column No:	Channel 9					6.91 g - 9th Level Calibration				
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
	0	0	0	3	-	6	9	4	2	9
	0	9	0	0	-	0	0	0	0	0
	0	8	0	0	-	0	0	0	3	2
	0	7	0	0	-	0	0	2	8	9
	0	6	0	0	-	0	0	8	7	7
	0	5	0	0	-	0	6	1	4	5
	0	4	0	0	-	2	5	0	7	2
	0	3	0	0	-	5	3	2	0	3
	0	2	0	0	-	8	6	6	1	8
	0	1	0	1	-	1	6	7	9	3
	1	1	0	1	-	0	5	3	5	8
	1	2	0	0	-	8	0	3	7	7
	1	3	0	0	-	5	0	1	0	6
	1	4	0	0	-	2	8	1	9	0
	1	5	0	0	-	0	9	7	5	6
	1	6	0	0	-	0	2	7	3	9
	1	7	0	0	-	0	0	5	7	8
	1	8	0	0	-	0	0	0	1	5
	1	9	0	0	-	0	0	0	0	0

- Column No. 1 - Designates polarity of signal; 1 - Positive, 0 - Negative
 2 - Designates amplitude levels 1 thru 9, each level is 3db apart
 3 to 10 - Designates time in seconds, with column 5 (dash) being the decimal point. Where columns 1 and 2 indicate zero (0) the numbers following register total time of data being analyzed

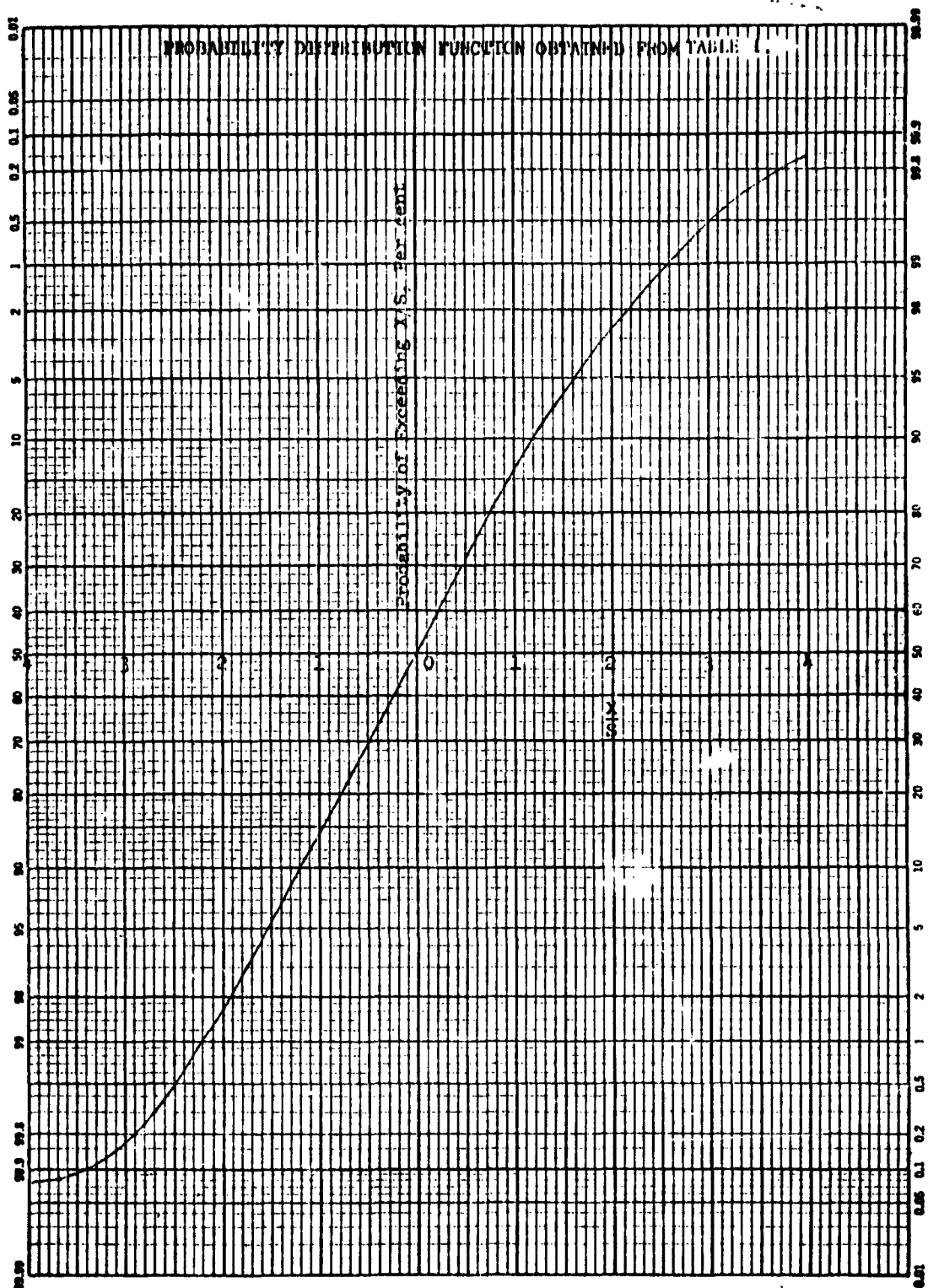


Figure 1: Probability Distribution Function Obtained from Table 1.

The ratio of adjacent levels is very nearly equal to the $\sqrt{2}$; thus, going up two levels is equivalent to doubling the amplitude.

In using the statistical counter, the actual value of the amplitude calibration assigned to the 9th level is such that the peak of the record being examined always falls between the 8th and 9th level, the indicated time above the 9th level is thus always 0.

6. DATA ANALYSIS AND RESULTS

The data to be examined represent acceleration. The integral of acceleration in respect to time is velocity. If the vehicle starts its run over the test course and finishes its run so that the difference in velocity at start and finish is 0, then the integral of acceleration over the time duration of the run is 0; and so the average acceleration during this time is 0. It follows that the probability-density function has an average value of 0. If the average value is 0, then by definition the root mean square (rms) of the acceleration is identical to the standard deviation of the probability-density function. This value is defined as "severity" and will be symbolized by S. The parameter S is hereinafter used as the primary control statistic. The square of S (S^2) is both statistically significant (variance) and mechanically significant (power).

In order to handle a large volume of data rapidly, a Bendix G15-D computer was programmed to produce the following results:

- a. S, assuming that the average acceleration was 0.
- b. S, computed about the average acceleration.

The S's obtained from the high-speed computer on options a and b were virtually identical, thus establishing that the rms acceleration and the standard deviation of the probability-density function were identical.

The 1st phase of the investigation was establishing the stationarity of the vibration environment. To this end a paved course was selected, since it was free of shock considerations. Several runs were made and 60-second loops were analyzed. The loops were then cut in half and each half analyzed. The halves were then cut in half again and analyzed. The conclusion reached on the basis of comparing S for the entire run to the S's obtained from the halves and quarters was that the process was stationary. Data are presented in Table II.

Table II. The Stationarity of the Automotive Vibration Environment

Vehicle: Carrier, personnel, full-tracked, armored, M113.
Course: Paved road.

Road Speed, mph	Loop	Acceleration, rms											
		Channel 2			Channel 3			Channel 4			Channel 5		
		60 Sec	30 Sec	15 Sec	60 Sec	30 Sec	15 Sec	60 Sec	30 Sec	15 Sec	60 Sec	30 Sec	15 Sec
8	1	0.271	0.270	0.271	0.362	0.370	0.380	0.394	0.403	0.401	0.348	0.347	0.350
				.274			0.366			0.414			0.350
			.260	.263		0.356	0.351		0.387	0.387		0.350	0.339
				.255			0.361			0.392			0.363
12	2	.549	.528	.545	0.490	0.485	0.502	0.593	0.598	0.584	0.725	0.685	0.695
				.518			0.487			0.610			0.689
			.581	.584		0.500	0.502		0.593	0.606		0.762	0.782
				.581			0.502			0.588			0.744
17	2	.652	.640	.660	0.708	0.699	0.713	0.848	0.844	0.820	0.954	0.923	0.934
				.643			0.689			0.868			0.919
			.649	.659		0.719	0.730		0.811	0.818		0.956	0.957
				.652			0.715			0.819			0.962
25	2	.934	.934	.928	1.035	1.039	1.023	1.391	1.438	1.415	1.584	1.573	1.576
				.953			1.060			1.489			1.625
			.931	.943		1.044	1.042		1.336	1.364		1.585	1.619
				.939			1.055			1.333			1.564

Several attempts were made to determine the probability-distribution function. The first, and least lucrative, was to plot the output of the statistical counter on probability paper. This type of display portrays a Gaussian distribution as a straight line. Initial plots indicated that the automotive vibration environment was not Gaussian, the population in the tails exceeds the Gaussian expectancy in some cases by at least two orders of magnitude. The labor involved in plotting the data was considerable, and a more fruitful approach was required. The high-speed computer program was revised to include a determination of the 4th moment of the probability-density function. This was divided by the square of the variance to produce a dimensionless statistic, M . The quantity, M , is very sensitive to the tail population and readily indicated the general shape of the probability-distribution curves. At this point some a priori considerations are necessary to understand the procedures that followed.

An acceleration run that produces a record that is a perfect sine wave would result in an M of 1.5. The ratio of the peak to the rms value of a sine wave is $\sqrt{2}$. The $\sqrt{2}$ is exactly the ratio of one level to the next level. Since the statistical counter is always set so the peak falls in the 8th level, the S for a sine wave would fall in the 7th level. The crest factor (ratio of peak to rms) is indicative of the level in which S falls, since the peak always falls in the 8th level. Additional consideration provides even more insight to this relationship. A perfect square wave has an M of 1, and a crest factor, C , of 1, thus

S and the peak fall in the same level. The statistic, M, is thus a measure of the central tendency of the probability-distribution function. The crest factor also is a measure of central tendency. It is apparent that, when S falls in one of the lower levels, the crest factor will be high as will be M.

The results of the high-speed computer runs were plotted to determine if a relationship actually existed between the level in which S fell, and M. Figure 2 shows the result. Although the correlation was not as strong as had been anticipated, the result was encouraging. One must remember that M is extremely sensitive to tail population. Very small changes in the tail population influence M radically, thus the large scatter was attributed to small differences in the tail population. If this hypothesis is true, then one could categorize and say that all records having an S that fell in a particular level had similar probability-distribution functions. Were this true, then a method could be evolved for determining both S, and the form of the probability-distribution function readily.

A new plot was made in which the percentage of time that the absolute value of the amplitude exceeded certain reference levels was plotted against S, where S was expressed in terms of the 1st level being 1. The results gave good correlation between S and the percentage of time above a reference level (see Figure 3). The means for determining S from the statistical counter data rapidly and with good accuracy had been established.

The next step was to determine if the probability-distribution function could be described. To this end, several records were plotted on probability paper. These records were selected so that they represented specific levels. The results were very encouraging. The general shape of the probability-distribution function is a function of the level in which S appears. This is shown in Figure 4.

As a practical consideration in describing the probability-distribution function, the following procedure was established. An arbitrary value of 1% was selected; this 1% was to be the percentage of time one could expect the absolute value of the acceleration to exceed nS . The coefficient n is thus an additional measure of the central tendency of the probability-density function. Values of n were selected from Figure 4 and plotted against the value of S that the probability-distribution function represented. The result is Figure 5, which provides a ready means of graphically describing the general nature of the probability-distribution function.

The feasibility of describing the automotive vibration environment in terms of S and the probability-distribution function was thus established. The problem remaining was to find a practical means of converting the data produced by the statistical counter to the parameters descriptive of the environment. To this end, the data graphically shown in Figure 3 were programmed into a high-speed computer. A least-square polynomial of the 3rd degree was passed through the data representing each reference level. The graphical results are shown in Figure 6. The computer program also produced the data tabulated in Table III. These data are based on the 9th level having a value of 1. The region of best fit of the cubic was centered in the region of 15% of the population exceeding the prescribed reference level.

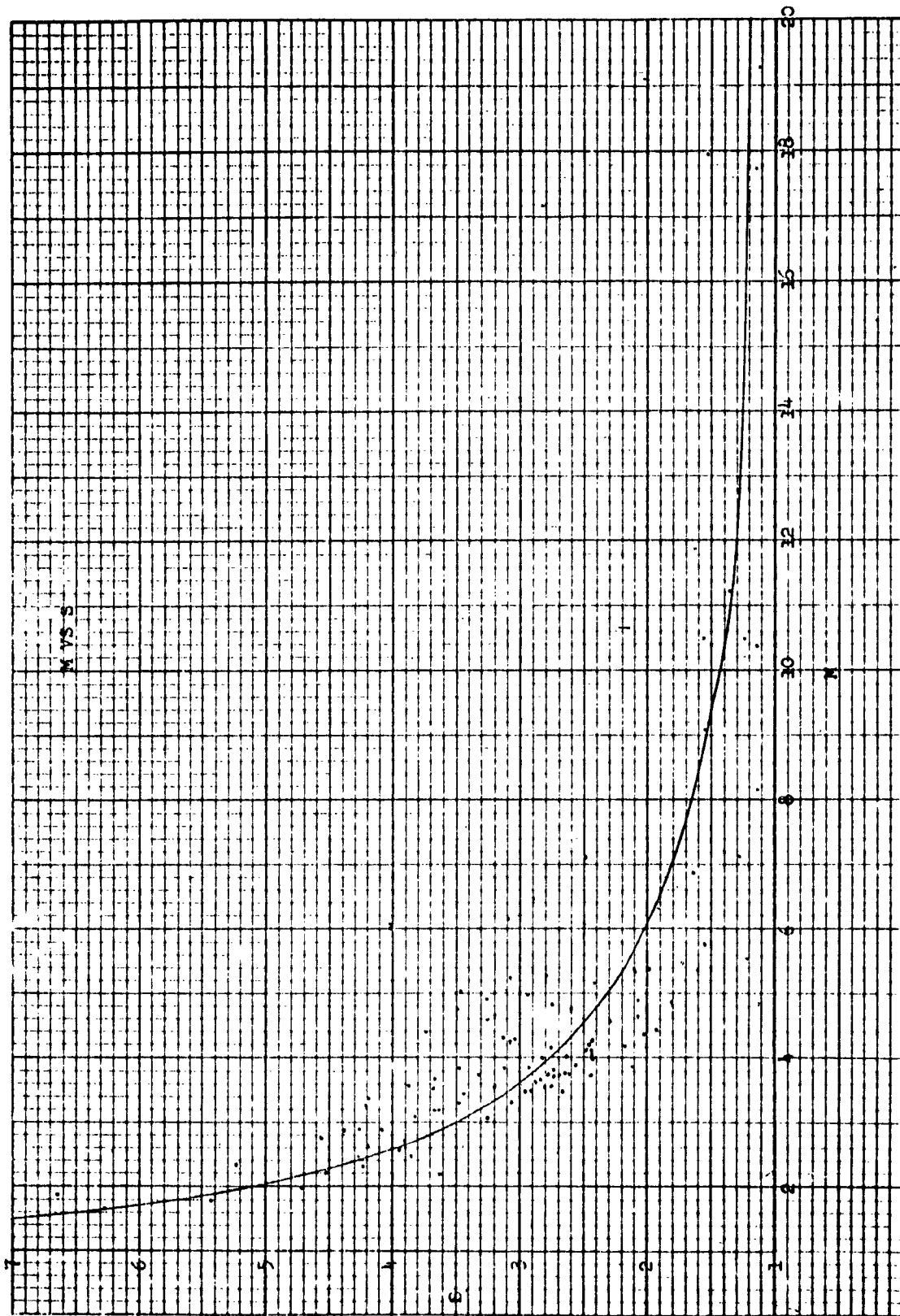


Figure 2: Relationship between M and the Level of S.

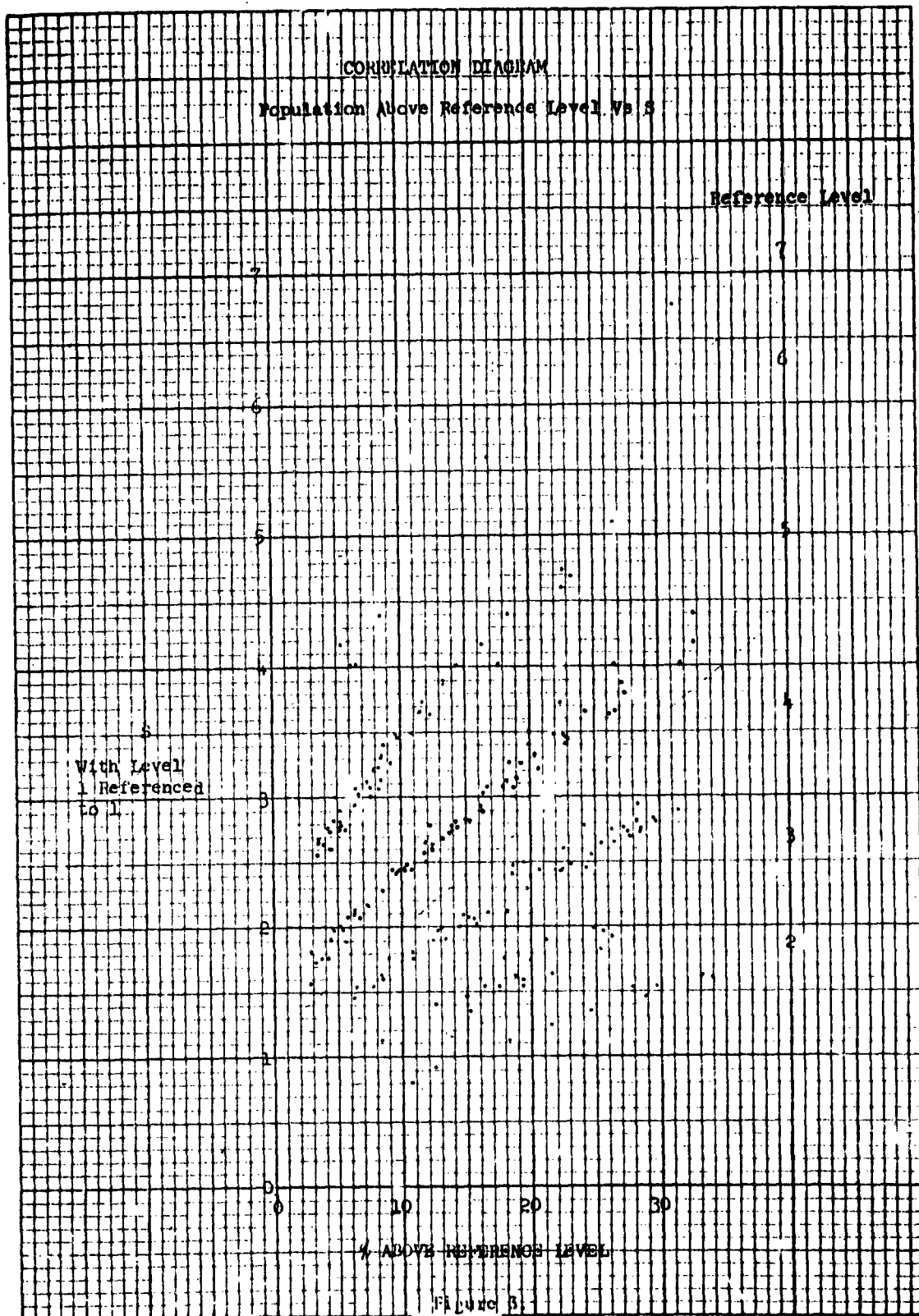


Figure 3.

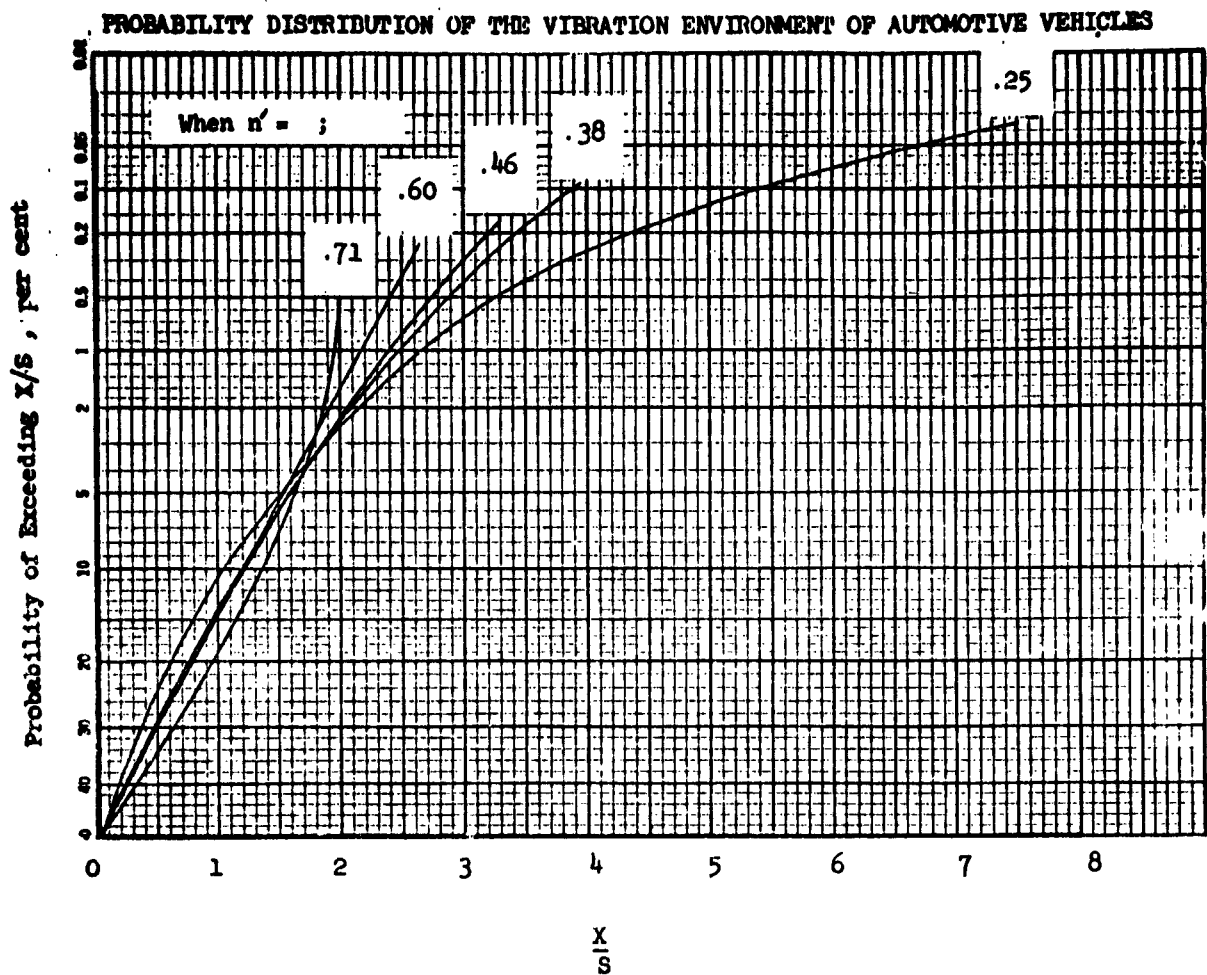


Figure 4: Probability Distribution of the Vibration Environment of Automotive Vehicles.

The data were generated upon the basis of absolute values, thus the 15% includes both the positive and negative levels. The determination of S from the statistical counter data is thus as follows:

- a. Scan the statistical counter data seeking the level representing about 7.5% of the total record time.
- b. Note the level, this is the reference level.
- c. Add the times in the positive and negative reference level, convert the sum to a percentage of the total record time.
- d. Enter Table III with the percentage and leave with S/K from the proper reference level.
- e. Multiply S/K by K , the calibration value assigned to the 9th level for the record. The result is S .

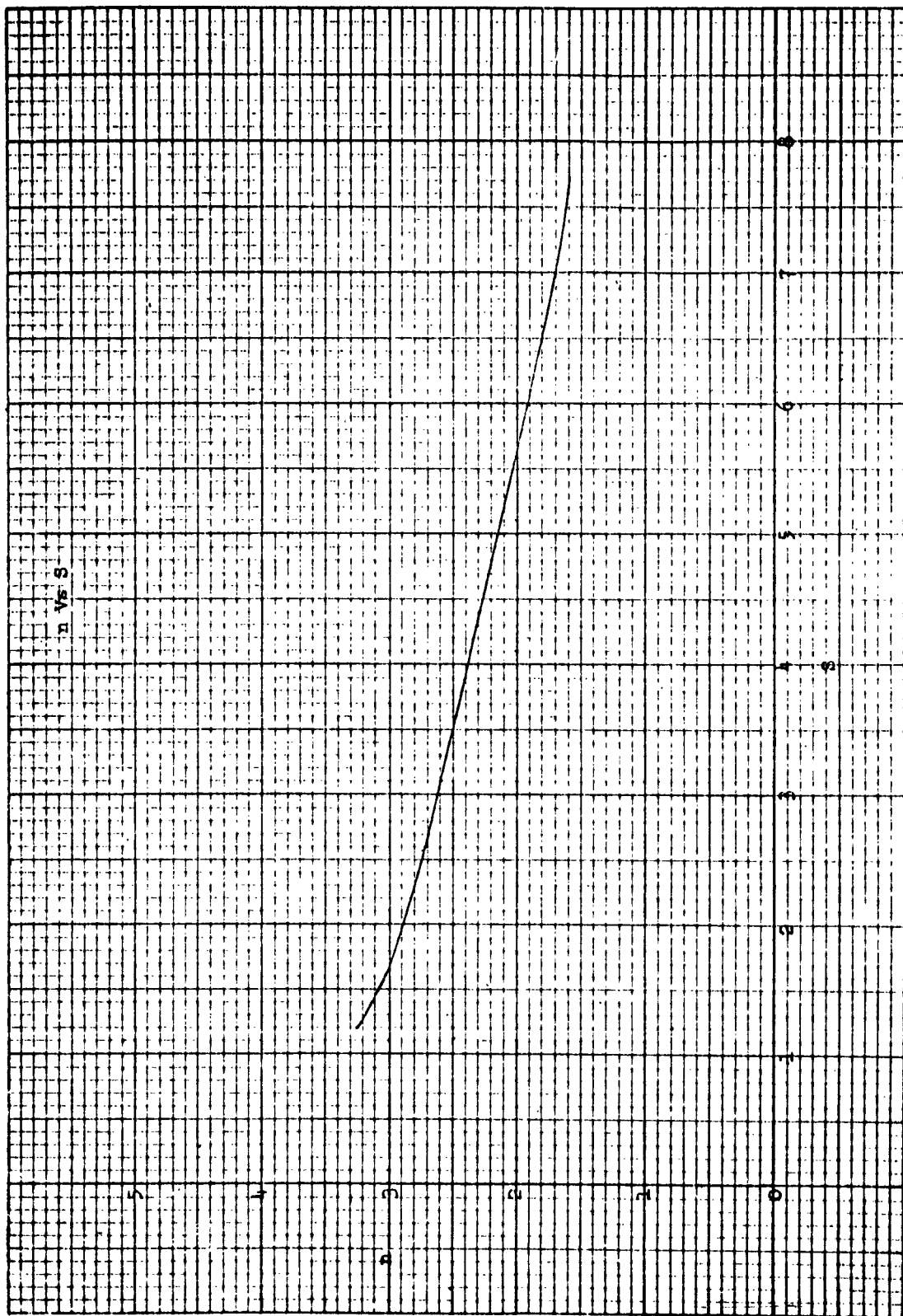


Figure 5: Values of n Plotted against Value of S .

REFERENCE CHART FOR ESTIMATING S FROM TAIL POPULATION

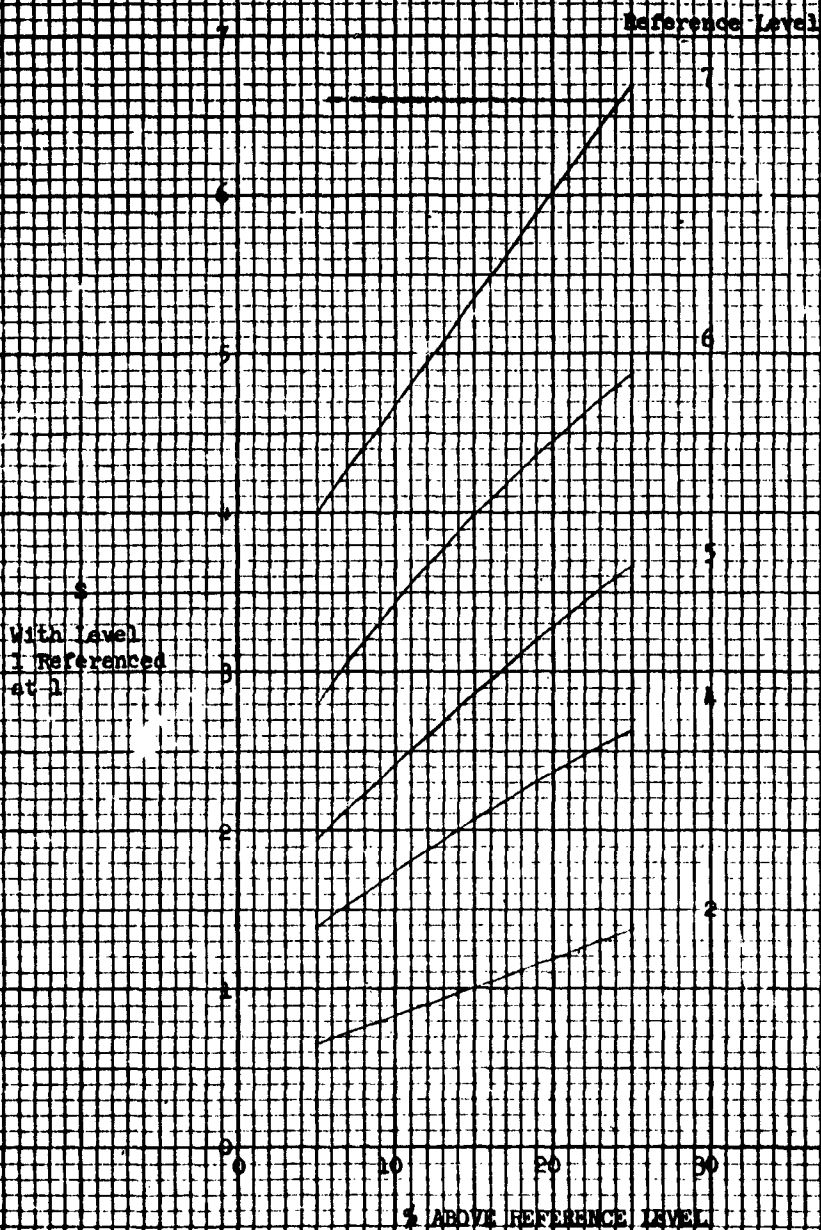


Figure 6: Reference Chart for Estimating S From Tail Population

Table III. Vibration Environment of Automotive Vehicles

Reference Level	Reference Levels																			
	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	21st
3.00	0.0392	21.8	0.0613	13.9	0.0800	0.25	10.7	0.1107	0.33	7.7	0.1581	0.43	5.4	0.2495	0.60	3.4				
3.25	0.0395	21.6	0.0616	13.9	0.0811	.26	10.5	.1123	.33	7.6	.1605	.44	5.3	.2497	.60	3.4				
3.50	0.0398	21.5	0.0619	13.8	0.0821	.26	10.4	.1139	.33	7.5	.1629	.44	5.2	.2500	.60	3.4				
3.75	0.0401	21.3	0.0622	13.7	0.0832	.26	10.3	.1155	.34	7.4	.1652	.45	5.2	.2503	.60	3.4				
4.00	0.0404	21.1	0.0626	13.6	0.0843	.27	10.1	.1171	.34	7.3	.1676	.45	5.1	.2508	.60	3.4				
4.25	0.0407	21.0	0.0630	13.6	0.0853	.27	10.0	.1187	.35	7.2	.1699	.46	5.0	.2514	.60	3.4				
4.50	0.0411	20.7	0.0634	13.5	0.0864	.27	9.9	.1203	.35	7.1	.1722	.46	5.0	.2520	.61	3.4				
4.75	0.0414	20.6	0.0638	13.4	0.0875	.27	9.8	.1219	.35	7.0	.1745	.47	4.9	.2527	.61	3.4				
5.00	0.0418	20.4	0.0643	13.3	0.0885	.28	9.6	.1234	.36	6.9	.1767	.47	4.8	.2536	.61	3.4				
5.25	0.0421	20.3	0.0647	13.2	0.0896	.28	9.5	.1250	.36	6.8	.1789	.47	4.8	.2545	.61	3.4				
5.50	0.0425	20.1	0.0652	13.1	0.0907	.28	9.4	.1266	.36	6.8	.1811	.48	4.7	.2554	.61	3.3				
5.75	0.0429	19.9	0.0657	13.0	0.0918	.28	9.3	.1281	.37	6.7	.1833	.48	4.7	.2565	.61	3.3				
6.00	0.0433	19.7	0.0662	12.9	0.0928	.29	9.2	.1296	.37	6.6	.1855	.49	4.6	.2576	.61	3.3				
6.25	0.0437	19.5	0.0667	12.8	0.0939	.29	9.1	.1312	.37	6.5	.1876	.49	4.6	.2588	.61	3.3				
6.50	0.0441	19.4	0.0673	12.7	0.0950	.29	9.0	.1327	.38	6.4	.1897	.49	4.5	.2602	.62	3.3				
6.75	0.0445	19.1	0.0679	12.6	0.0961	.29	8.9	.1342	.38	6.4	.1918	.50	4.5	.2615	.62	3.3				
7.00	0.0450	19.0	0.0685	12.5	0.0971	.30	8.8	.1357	.38	6.3	.1939	.50	4.4	.2629	.62	3.2				
7.25	0.0454	18.8	0.0691	12.4	0.0981	.30	8.7	.1372	.39	6.2	.1960	.50	4.4	.2644	.62	3.2				
7.50	0.0459	18.6	0.0697	12.3	0.0993	.30	8.6	.1387	.39	6.2	.1980	.51	4.3	.2660	.62	3.2				
7.75	0.0464	18.4	0.0703	12.1	0.1003	.30	8.5	.1402	.39	6.1	.2000	.51	4.3	.2676	.62	3.2				
8.00	0.0468	18.2	0.0710	12.0	0.1014	.31	8.4	.1417	.40	6.0	.2020	.52	4.2	.2693	.63	3.2				
8.25	0.0473	18.1	0.0717	11.9	0.1025	.31	8.3	.1432	.40	6.0	.2040	.52	4.2	.2710	.63	3.2				
8.50	0.0480	17.8	0.0723	11.8	0.1035	.31	8.3	.1447	.40	5.9	.2060	.52	4.2	.2728	.63	3.1				
8.75	0.0483	17.7	0.0730	11.7	0.1046	.31	8.2	.1461	.41	5.9	.2079	.53	4.1	.2746	.63	3.1				
9.00	0.0488	17.5	0.0737	11.6	0.1057	.32	8.1	.1476	.41	5.8	.2099	.53	4.1	.2766	.63	3.1				
9.25	0.0493	17.3	0.0745	11.5	0.1067	.32	8.0	.1490	.41	5.7	.2118	.53	4.0	.2785	.64	3.1				
9.50	0.0496	17.1	0.0752	11.4	0.1078	.32	8.0	.1505	.42	5.7	.2137	.54	4.0	.2805	.64	3.0				
9.75	0.0503	17.0	0.0759	11.3	0.1089	.32	7.8	.1519	.42	5.6	.2158	.54	4.0	.2826	.64	3.0				
10.00	0.0509	16.8	0.0768	11.1	0.1099	.33	7.8	.1534	.42	5.6	.2174	.54	3.9	.2847	.64	3.0				
10.25	0.0514	16.6	0.0774	11.0	0.1110	.33	7.7	.1548	.43	5.5	.2192	.55	3.9	.2868	.64	3.0				
10.50	0.0520	16.4	0.0782	10.9	0.1120	.33	7.6	.1562	.43	5.5	.2210	.55	3.9	.2890	.65	3.0				
10.75	0.0525	16.2	0.0790	10.8	0.1131	.33	7.6	.1577	.43	5.4	.2229	.56	3.8	.2913	.65	2.9				
11.00	0.0531	16.1	0.0798	10.7	0.1141	.33	7.5	.1591	.44	5.4	.2247	.56	3.8	.2935	.65	2.9				
11.25	0.0536	16.0	0.0806	10.6	0.1152	.34	7.4	.1605	.44	5.3	.2264	.56	3.8	.2958	.65	2.9				
11.50	0.0542	15.8	0.0814	10.5	0.1162	.34	7.3	.1619	.44	5.3	.2282	.56	3.7	.2982	.65	2.9				
11.75	0.0548	15.6	0.0822	10.4	0.1173	.34	7.3	.1633	.44	5.2	.2299	.57	3.7	.3005	.66	2.8				
12.00	0.0553	15.5	0.0830	10.3	0.1183	.34	7.2	.1647	.45	5.2	.2317	.57	3.7	.3029	.66	2.8				
12.25	0.0559	15.3	0.0838	10.2	0.1193	.35	7.2	.1660	.45	5.1	.2334	.57	3.7	.3054	.66	2.8				
12.50	0.0565	15.1	0.0846	10.1	0.1204	.35	7.1	.1674	.45	5.1	.2351	.58	3.6	.3078	.67	2.8				
12.75	0.0571	15.0	0.0854	10.0	0.1214	.35	7.0	.1688	.45	5.1	.2366	.58	3.6	.3103	.67	2.8				
13.00	0.0577	14.9	0.0863	9.9	0.1224	.35	7.0	.1702	.46	5.0	.2385	.58	3.6	.3128	.68	2.7				
13.25	0.0583	14.7	0.0871	9.8	0.1235	.36	7.0	.1715	.46	5.0	.2401	.58	3.6	.3153	.68	2.7				
13.50	0.0589	14.5	0.0880	9.7	0.1245	.36	6.9	.1729	.46	4.9	.2418	.59	3.5	.3179	.68	2.7				
13.75	0.0595	14.4	0.0888	9.6	0.1255	.36	6.8	.1742	.46	4.9	.2434	.59	3.5	.3204	.68	2.7				

Table III (Cont'd)

Above Reference Level	Reference Levels									
	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
	S/A	C	S/A	C	S/A	C	S/A	C	S/A	C
14.00	0.0601	14.2	0.0896	0.28	9.5	0.1265	0.36	6.8	0.1756	0.47
14.25	0.0607	14.0	0.0905	0.28	9.4	0.1275	0.36	6.7	0.1769	0.47
14.50	0.0614	13.9	0.0913	0.28	9.4	0.1286	0.37	6.6	0.1783	0.47
14.75	0.0620	13.8	0.0922	0.28	9.3	0.1296	0.37	6.6	0.1796	0.47
15.00	0.0626	13.7	0.0930	0.29	9.2	0.1306	0.37	6.5	0.1810	0.48
15.25	0.0632	13.5	0.0939	0.29	9.1	0.1316	0.37	6.5	0.1829	0.48
15.50	0.0639	13.4	0.0947	0.29	9.0	0.1329	0.38	6.4	0.1836	0.48
15.75	0.0645	13.2	0.0956	0.29	8.9	0.1336	0.38	6.4	0.1849	0.48
16.00	0.0651	13.1	0.0964	0.29	8.9	0.1345	0.38	6.3	0.1862	0.49
16.25	0.0658	13.0	0.0972	0.30	8.8	0.1355	0.38	6.3	0.1876	0.49
16.50	0.0664	12.9	0.0981	0.30	8.7	0.1365	0.39	6.3	0.1889	0.49
16.75	0.0670	12.7	0.0989	0.30	8.6	0.1375	0.39	6.2	0.1902	0.49
17.00	0.0678	12.6	0.0997	0.30	8.6	0.1384	0.39	6.2	0.1915	0.50
17.25	0.0685	12.5	0.1006	0.30	8.5	0.1394	0.39	6.1	0.1928	0.50
17.50	0.0690	12.3	0.1014	0.31	8.4	0.1404	0.39	6.1	0.1941	0.50
17.75	0.0696	12.3	0.1022	0.31	8.4	0.1413	0.40	6.0	0.1954	0.50
18.00	0.0702	12.2	0.1030	0.31	8.3	0.1423	0.40	6.0	0.1966	0.51
18.25	0.0709	12.0	0.1038	0.31	8.2	0.1432	0.40	6.0	0.1979	0.51
18.50	0.0715	11.9	0.1046	0.31	8.2	0.1441	0.40	5.9	0.1992	0.51
18.75	0.0721	11.8	0.1053	0.31	8.1	0.1451	0.40	5.9	0.2005	0.51
19.00	0.0728	11.7	0.1061	0.32	8.0	0.1460	0.41	5.8	0.2018	0.52
19.25	0.0734	11.6	0.1069	0.32	8.0	0.1469	0.41	5.8	0.2030	0.52
19.50	0.0741	11.5	0.1076	0.32	7.9	0.1478	0.41	5.8	0.2043	0.52
19.75	0.0747	11.4	0.1084	0.32	7.9	0.1488	0.41	5.7	0.2056	0.52
20.00	0.0753	11.3	0.1091	0.32	7.8	0.1497	0.42	5.7	0.2068	0.53
20.25	0.0760	11.2	0.1098	0.32	7.8	0.1506	0.42	5.7	0.2081	0.53
20.50	0.0766	11.1	0.1105	0.33	7.7	0.1514	0.42	5.6	0.2093	0.53
20.75	0.0772	11.1	0.1112	0.33	7.7	0.1523	0.42	5.6	0.2106	0.53
21.00	0.0779	11.0	0.1119	0.33	7.6	0.1532	0.42	5.6	0.2118	0.54
21.25	0.0785	10.9	0.1126	0.33	7.6	0.1541	0.43	5.5	0.2131	0.54
21.50	0.0791	10.8	0.1133	0.33	7.5	0.1549	0.43	5.5	0.2143	0.54
21.75	0.0797	10.7	0.1139	0.33	7.5	0.1558	0.43	5.5	0.2156	0.54
22.00	0.0803	10.6	0.1145	0.34	7.5	0.1567	0.43	5.4	0.2168	0.54
22.25	0.0809	10.5	0.1151	0.34	7.4	0.1575	0.43	5.4	0.2181	0.55
22.50	0.0815	10.5	0.1157	0.34	7.4	0.1583	0.43	5.4	0.2193	0.55
22.75	0.0821	10.4	0.1163	0.34	7.3	0.1592	0.44	5.4	0.2205	0.55
23.00	0.0827	10.3	0.1169	0.34	7.3	0.1600	0.44	5.3	0.2218	0.55
23.25	0.0833	10.3	0.1174	0.34	7.3	0.1608	0.44	5.3	0.2230	0.56
23.50	0.0839	10.2	0.1180	0.34	7.2	0.1616	0.44	5.3	0.2242	0.56
23.75	0.0845	10.1	0.1185	0.34	7.2	0.1624	0.44	5.3	0.2255	0.56
24.00	0.0851	10.0	0.1190	0.35	7.2	0.1632	0.44	5.2	0.2267	0.56
24.25	0.0857	10.0	0.1194	0.35	7.2	0.1640	0.45	5.2	0.2279	0.56
24.50	0.0862	9.9	0.1199	0.35	7.1	0.1648	0.45	5.2	0.2291	0.57
24.75	0.0868	9.8	0.1203	0.35	7.1	0.1656	0.45	5.1	0.2303	0.57
25.00	0.0874	9.8	0.1207	0.35	7.1	0.1663	0.45	5.1	0.2316	0.57

The determination of the probability-distribution function is quite simple. Figure 5 shows the relationship between n and S ; from this the product nS was formed, this was then divided by the absolute value of the 9th level (15.85) so that the result is n^1 where

$$n^1 = \frac{nS}{K}$$

The value n^1 , which is a function of S , is entered on Table III and represents a description of the general configuration of the probability-distribution function. The value n^1 is shown in Figure 4 to identify the probability-distribution function.

The procedure for identifying the probability-distribution function is as follows:

- a. Using the percentage established in determining S , enter Table III, leaving with n^1 from the appropriate reference level.
- b. Multiply n^1 by K ; this is the absolute value of the acceleration which has been exceeded 1% of the time.
- c. Enter Figure 4 with n^1 , noting the form of the probability-distribution function.

One more value is of interest, this is the peak acceleration or crest value. The crest always falls between the 8th and 9th level. Assigning a value of 1 to the 9th level, the 8th level has a relative value of 0.708. The average is 0.854, thus the average crest value reported can be off by 0.146 or 17.12%. The crest value will be reported simply as $0.854 K \pm 17.12\%$. The crest factor is of interest and is derived simply. In terms of the 9th level being 1, the crest factor is 0.854 divided by S , but S is given in terms of the 9th level in Table III. The entries in Table III under C (crest factor) reflect this division.

6. ACCURACY OF RESULTS

The question of the accuracy of estimating S from Table III arises. As a by-product of the curve-fitting process, via the high-speed computer, the standard deviations of the individual data points from the fitted curves were obtained. Table IV shows the error expectancy based on estimating S from Table III.

Table IV shows an entry indicating the number of data points available for analysis. Note that levels 2, 3, and 7 show few data points. More data are required in these levels to substantiate the results contained herein.

Table IV. Error Expectancy in Estimating S from Figure 5

Ref Level	No. of Data Points	$\frac{S}{K}$ Range of K	Std Dev of Data Points	Range of Error, % (One Std Dev)	Error at 15% of Reference Level, (One Std Dev)
2	10	0.0392 to 0.0874	0.0021	^a 5.4 to 2.4	^a 3.4
3	17	.0613 to .1207	.0058	9.6 to 4.8	6.2
4	49	.0800 to .1663	.0049	6.1 to 2.9	3.8
5	50	.1107 to .2316	.0056	5.1 to 2.4	3.1
6	49	.1581 to .3088	.0061	3.9 to 2.0	2.4
7	6	.2495 to .4222	.0088	3.5 to 2.1	2.6

^aLow error attributed to lack of sufficient samples to adequately describe conditions.

7. LIMITATIONS OF ANALYSIS

The preceding analysis does not include all the data collected. The excluded records are distinctly shock response: S falls well below the 1st level; some of these records have less than 5% of the population in excess of the 1st level. The question arises, "When can one consider the record to contain shock?" It should be noted that the accuracy of estimating S from the 3rd level as a reference is poorer than the accuracy associated with the higher levels. The exception is the 2nd level for which too few data points are available for conclusive results. The inference is that when S falls in the 3rd level or below, shock may be present. An examination of spectral plots indicates like results, the spectral plots seem to indicate that the line of delineation should be drawn when S falls between levels 2 and 3. This leads to the establishment of a numerical criterion that can be added to the definition of shock response. Since the crest is between the 8th and 9th levels, and S lies between the 2nd and 3rd levels for shock response, approximately six levels represent the crest factor, i.e., 18 db, thus crest factors of 8 or above are indicative of shock response. The reference chart for obtaining S (Table III), can be used when limited amounts of shock are present, but dilution of precision must be anticipated when the crest factor exceeds 8.

8. APPLICATION OF METHOD

As the primary objective was to provide a means of describing the automotive vehicular vibration environment, a practical application of the results of this study is in order. Accelerometers, with their sensing axis oriented in the vertical plane, were located in the cargo bed of an M35 truck.

The vehicle was then operated at various speeds over a variety of test courses (Appendix A). The maximum vehicle speed on each course was established in one of five ways:

- a. The speed at which the most severe conditions are transmitted to the test item.
- b. A road speed that is the most severe the driver can withstand.
- c. A speed above which it is not safe to operate the vehicle because it becomes unstable.
- d. The maximum speed that can be obtained without damage to the vehicle running gear.
- e. Maximum speed of vehicle.

From the acquired data values of S, 1% of time level, probability-distribution function and crest were determined. A plot (Figure 7) was made of the severest environment at each road speed. The data show:

- (1) The level paved road to be the least severe of any of the test courses.
- (2) Using the level paved course as a base line, the cargo bed of the M35 presents a rather severe environment when the vehicle traverses rough terrain.
- (3) Above 4 mph and up to 24 mph, the crest amplitudes were extremely high.
- (4) A resonant condition (ratio of crest to rms = 1.41) was approached at 28 mph on the level paved road with a ratio of crest to rms of 3.

9. CONCLUSIONS

- a. The automotive vehicular vibration amplitude environment is non-Gaussian.
- b. A method has been developed to describe the automotive vehicular vibration amplitude environment.
- c. Reference charts for rapid determination of standard deviation of amplitude and the probability-distribution function have been developed.

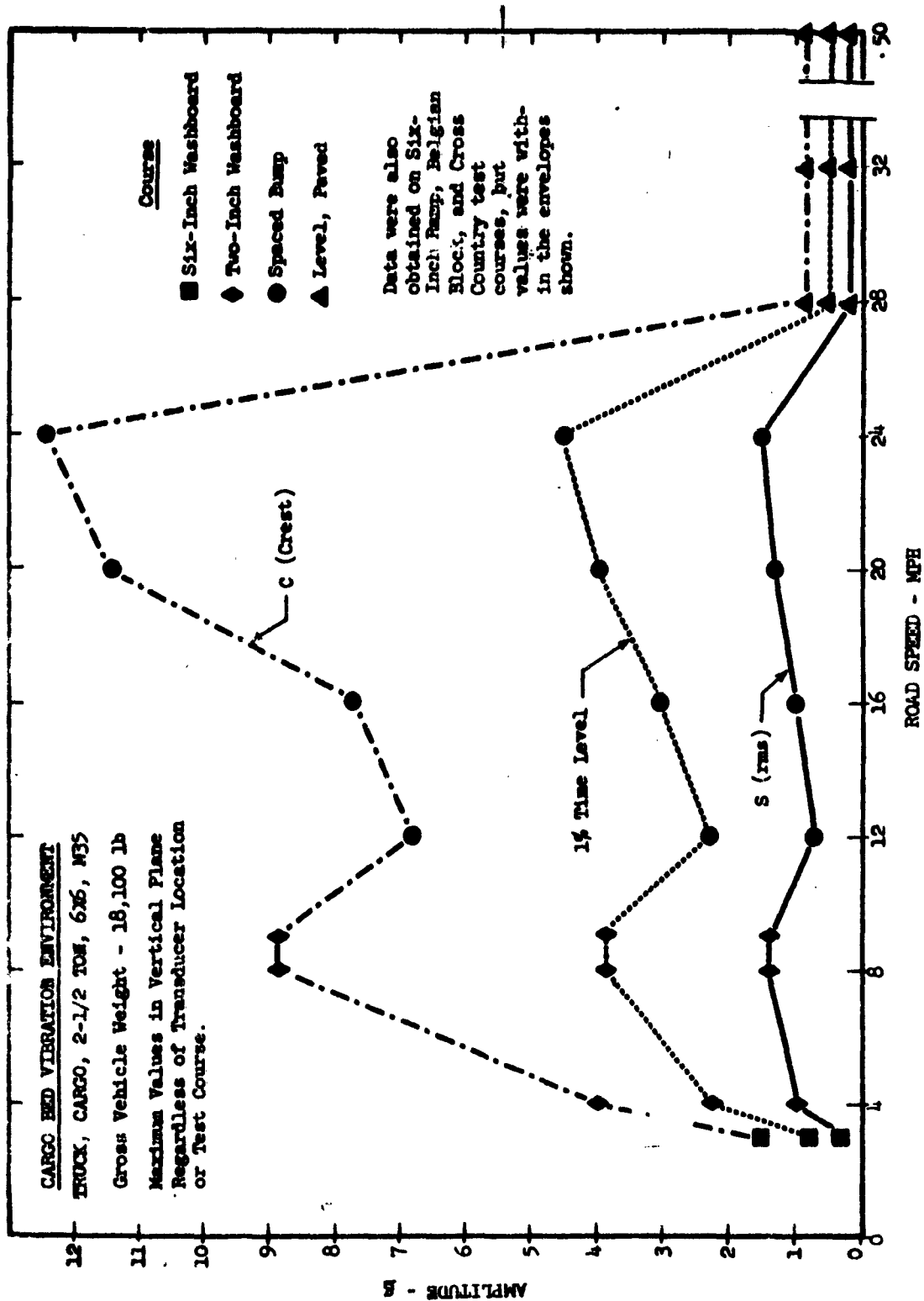
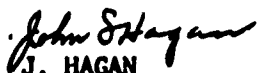


Figure 7

10. RECOMMENDATION

The method developed in this report be used to describe the vibration amplitude of automotive vehicles.

SUBMITTED:



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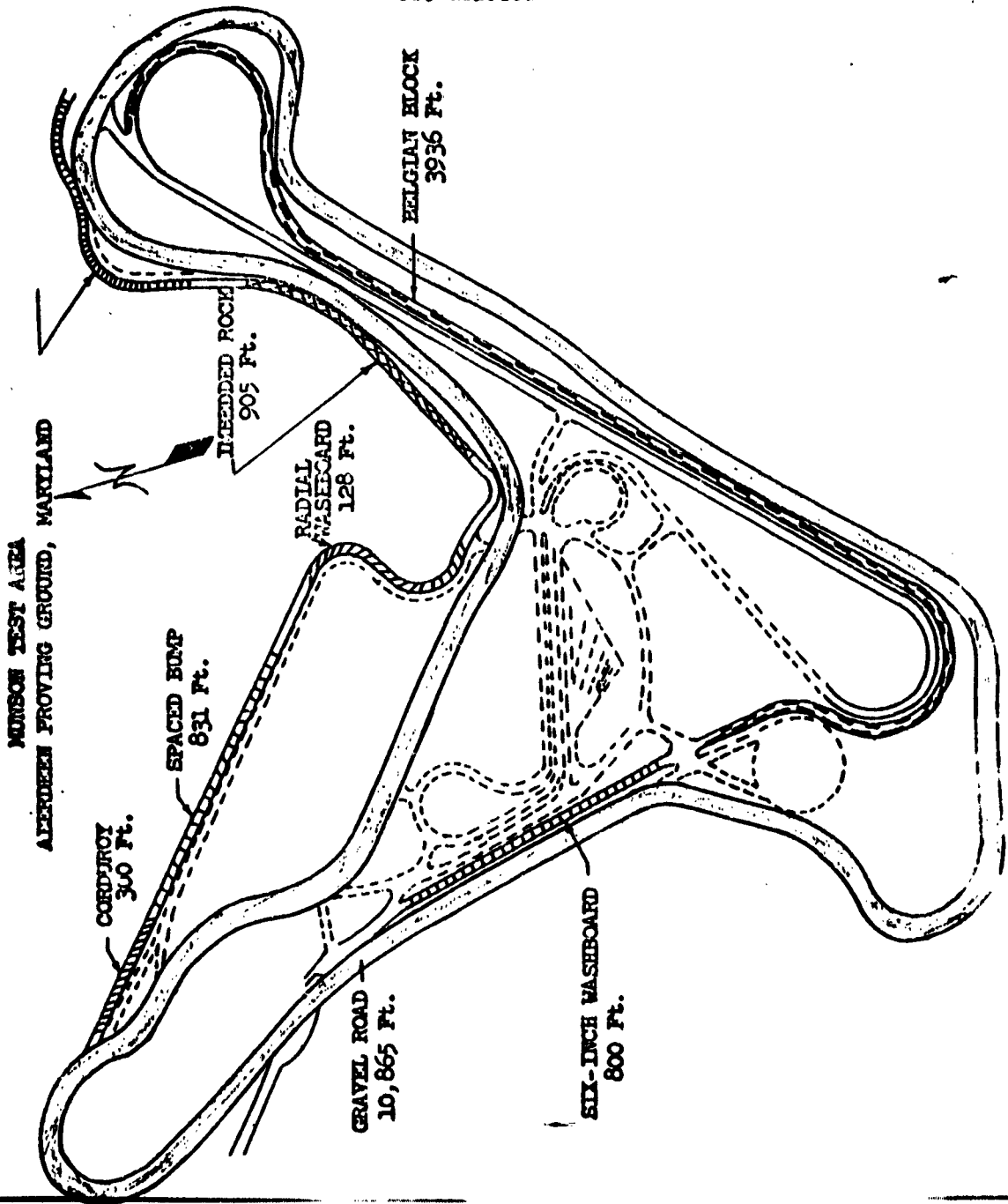
APPROVED:



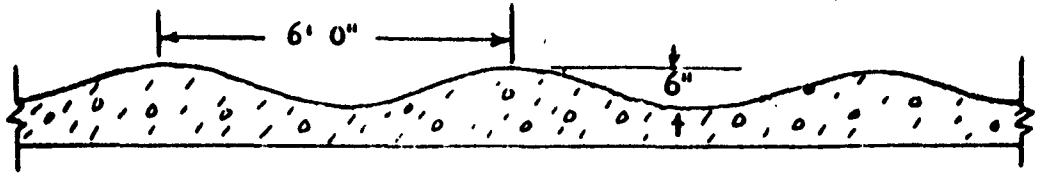
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APPENDIX A

Test Courses

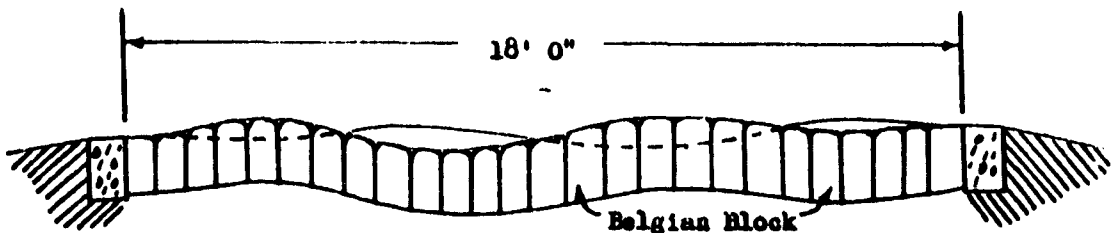


SIX-INCH WASHBOARD COURSE



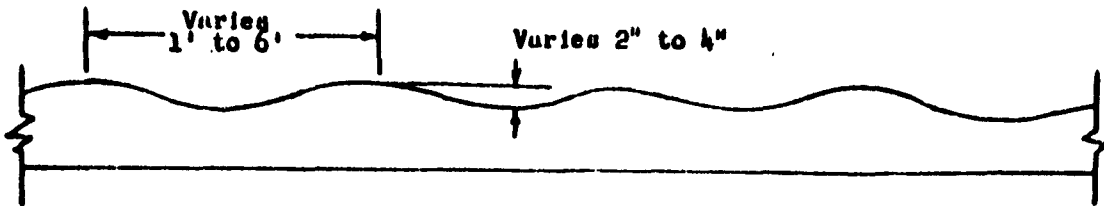
The profile approaches a sine wave with a double amplitude of six inches and a complete cycle occurring every six feet for a distance of 800 feet. The course surface is concrete.

BELGIAN BLOCK COURSE



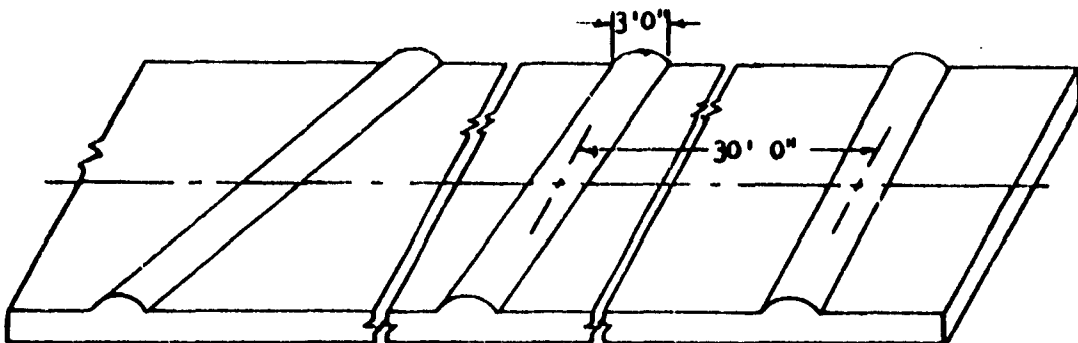
This course is a cobblestone road which provides an irregular and bumpy surface. The individual cobblestones average approximately five inches in width. The course irregularities, which not only vary along the length (3936 feet) of the course but also across its width, have crests of about three inches. The crests are such that a vehicle traveling over them is subjected to both pitching and rolling motions.

RADIAL WASHBOARD COURSE

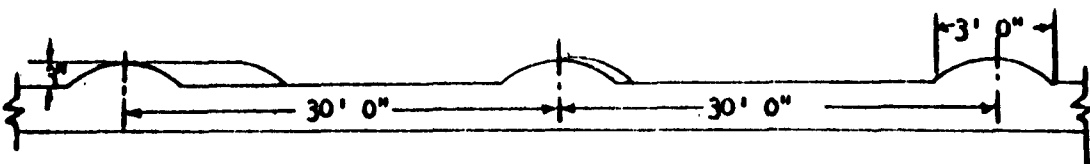


Two 90 degrees radial turns make up the Radial Washboard Course along with symmetrical bumps which vary from two to four inches in height and from one to six feet from crest to crest. The course is 128 feet long and 20 feet wide.

SPACED BUMP COURSE



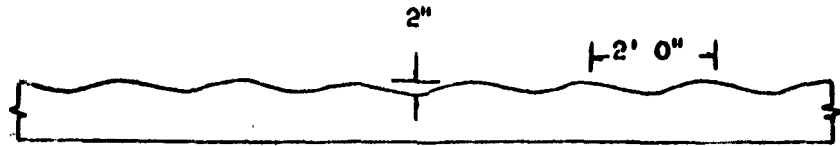
ISOMETRIC VIEW



LONGITUDINAL SECTION

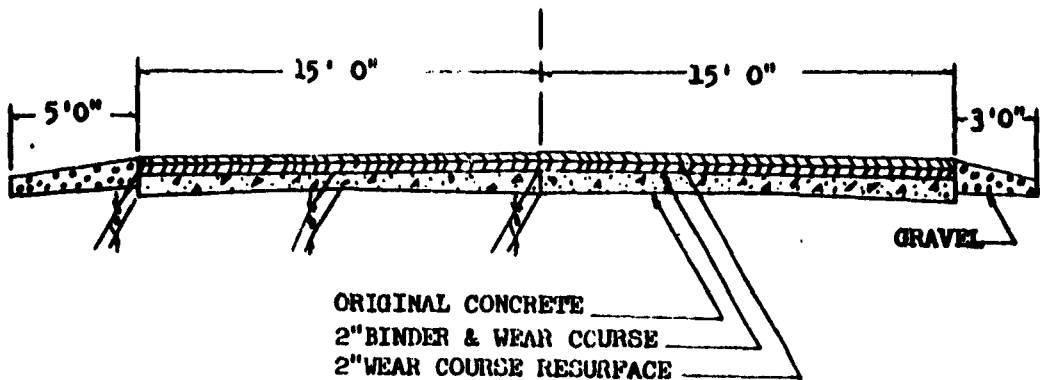
This course consists of a series of rounded bumps three inches high by three feet wide spaced at intervals of 30 feet along the centerline of the course. The bumps make the following angles with respect to the centerline of the course: 90°, 90°, 67°, 52°, 90°, 90°, 113°, 128°, 90°, 90°, this sequence continues for a total of twenty six bumps or three cycles for a total of 831 feet.

TWO-INCH WASHBOARD COURSE



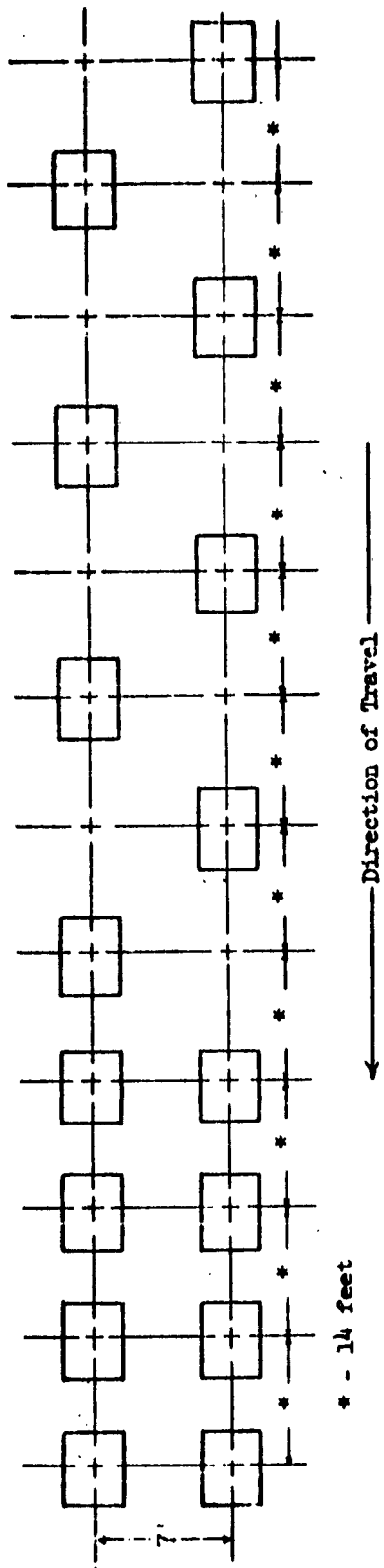
The profile approaches a sine wave with a double amplitude of two inches and a complete cycle occurring every two feet to a distance of approximately 300 feet. The course surface is concrete.

PEPPIYMAN STRAIGHTAWAY

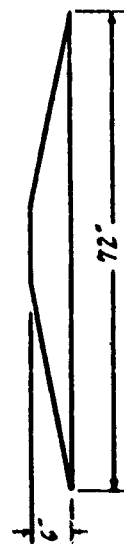
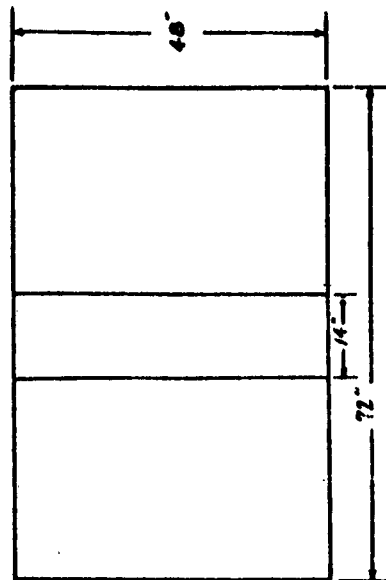


The paved straightaway is essentially a level road, three miles in length, with banked turn-around loops at each end. This course is used where high speed as well as tests requiring long periods of uninterrupted operation are desired.

DIAGRAM OF SPACING FOR RAMP COURSE
(Ramps Placed on Bituminous Concrete Surface)



A-5
D-30



Ramp Dimensions

Development and Proof Services

AUTOMOTIVE ENGINEERING LABORATORIES

REPORT ON

**A STUDY ESTABLISHING METHODOLOGY
DESCRIBING THE AUTOMOTIVE VEHICULAR
VIBRATION AMPLITUDE ENVIRONMENT**

ADDENDUM to Report No. DPS-657

JUNE 1963



*Aberdeen Proving Ground
Maryland*

Report DFB-657 stated more data were required to substantiate the results for reference levels 2, 3, and 7 of the Vibration Table III on pages 17 and 18 of that report. Since publication, additional data have been acquired for these three levels. These data appear here in Table III (Revised). The affect of these additional samples on the error expectancy, based on estimating S from Figure 5, D&FS Report No. 657 is contained in Table IV (Revised).

When originally published, Table III was based only on accelerometer data acquired for the vehicle frame or hull. Table III (Revised) in this addendum was derived using the same type of data. It has subsequently been found that estimates of S are also valid for the following types of data:

- a. Acceleration data for gear mounted on-board the vehicle; i.e., packaged electronics, missile warheads, motors and other related equipment. The on-board gear tested had many degrees of freedom.
- b. Rate of angular change data (rate gyros); i.e., pitch and roll of the vehicle.
- c. Uniaxial strain-gage data on vehicle frame and suspension parts.
- d. The above data as analyzed through 0.2 to 10 and 0.2 to 100 cps pass-band filters.

The error expectancy of S for each of the a, b, c, and d above, estimated from Table III (Revised) as compared with the calculated value of S is shown on Table V. These error expectancies are a composite of the error expectancies of the different reference levels. Because all of the reference levels may not be used for any one type of data, the error expectancies of the a, b, c, and d above may not coincide with the error expectancies of the different reference levels in Table IV. The majority of the data points for each of the a, b, c, and d above fell in reference levels 5, 6, and 7.

Table III. (Revised April 1963)
Vibration Environment of Automotive Vehicles

\$ Above Reference Level	1st			2nd			3rd			4th			5th			6th			7th		
	S/K	n ²	C	S/K	n ²	C	S/K	n ²	C	S/K	n ²	C	S/K	n ²	C	S/K	n ²	C	S/K	n ²	C
3.00	0.0676		17.9	0.0566		15.1	0.0800	0.25	10.7	0.1107	0.33	7.7	0.1581	0.43	5.4	0.2423	0.59	3.9			
3.25	0.0682		17.7	0.0579		14.7	0.0811	0.26	10.5	0.1123	0.33	7.6	0.1605	0.44	5.3	0.2462	0.60	3.5			
3.50	0.0688		17.5	0.0592		14.4	0.0821	0.26	10.4	0.1139	0.33	7.5	0.1629	0.44	5.2	0.2500	0.60	3.4			
3.75	0.0693		17.3	0.0605		14.1	0.0832	0.26	10.3	0.1155	0.34	7.4	0.1652	0.45	5.2	0.2537	0.61	3.4			
4.00	0.0699		17.1	0.0617		13.8	0.0843	0.27	10.1	0.1171	0.34	7.3	0.1676	0.45	5.1	0.2573	0.61	3.3			
4.25	0.0705		16.9	0.0629		13.6	0.0853	0.27	10.0	0.1187	0.35	7.2	0.1699	0.46	5.0	0.2608	0.62	3.3			
4.50	0.0710		16.7	0.0641	0.22	13.3	0.0864	0.27	9.9	0.1203	0.35	7.1	0.1722	0.46	5.0	0.2643	0.62	3.2			
4.75	0.0716		16.6	0.0653	0.22	13.1	0.0875	0.27	9.8	0.1219	0.35	7.0	0.1745	0.47	4.9	0.2676	0.63	3.2			
5.00	0.0722		16.4	0.0664	0.22	12.9	0.0885	0.28	9.6	0.1234	0.36	6.9	0.1767	0.47	4.8	0.2709	0.63	3.2			
5.25	0.0727		16.2	0.0675	0.23	12.6	0.0896	0.28	9.5	0.1250	0.36	6.8	0.1789	0.47	4.8	0.2741	0.63	3.1			
5.50	0.0733		16.0	0.0686	0.23	12.4	0.0907	0.28	9.4	0.1266	0.36	6.7	0.1811	0.48	4.7	0.2773	0.64	3.1			
5.75	0.0739		15.8	0.0697	0.23	12.2	0.0918	0.28	9.3	0.1281	0.37	6.7	0.1833	0.48	4.7	0.2803	0.64	3.0			
6.00	0.0744		15.7	0.0708	0.24	12.1	0.0928	0.29	9.2	0.1296	0.37	6.6	0.1855	0.49	4.6	0.2832	0.65	3.0			
6.25	0.0750		15.5	0.0718	0.24	11.9	0.0939	0.29	9.1	0.1312	0.37	6.5	0.1876	0.49	4.5	0.2861	0.65	3.0			
6.50	0.0756		15.4	0.0729	0.24	11.7	0.0950	0.29	9.0	0.1327	0.38	6.4	0.1897	0.49	4.5	0.2891	0.65	3.0			
6.75	0.0761		15.2	0.0739	0.24	11.6	0.0961	0.29	8.9	0.1342	0.38	6.4	0.1918	0.50	4.4	0.2918	0.66	2.9			
7.00	0.0767		15.1	0.0749	0.24	11.4	0.0971	0.30	8.8	0.1357	0.38	6.3	0.1939	0.50	4.4	0.2945	0.66	2.9			
7.25	0.0772		14.9	0.0759	0.25	11.2	0.0981	0.30	8.7	0.1372	0.39	6.2	0.1960	0.50	4.4	0.2972	0.66	2.8			
7.50	0.0778		14.8	0.0768	0.25	11.1	0.0993	0.30	8.6	0.1387	0.39	6.2	0.1980	0.51	4.3	0.2997	0.67	2.8			
7.75	0.0783		14.6	0.0778	0.25	11.0	0.1003	0.30	8.5	0.1402	0.39	6.1	0.2000	0.51	4.3	0.3022	0.67	2.8			
8.00	0.0789		14.5	0.0787	0.25	10.8	0.1014	0.31	8.4	0.1417	0.40	6.0	0.2020	0.52	4.2	0.3047	0.67	2.8			
8.25	0.0795		14.4	0.0796	0.26	10.7	0.1025	0.31	8.3	0.1432	0.40	6.0	0.2040	0.52	4.2	0.3070	0.67	2.8			
8.50	0.0800		14.2	0.0805	0.26	10.6	0.1035	0.31	8.3	0.1447	0.40	5.9	0.2060	0.52	4.2	0.3093	0.67	2.7			
8.75	0.0806		14.1	0.0814	0.26	10.5	0.1046	0.31	8.2	0.1461	0.41	5.9	0.2079	0.53	4.1	0.3116	0.68	2.7			
9.00	0.0811		14.0	0.0822	0.26	10.4	0.1057	0.32	8.1	0.1476	0.41	5.8	0.2099	0.53	4.0	0.3139	0.68	2.7			
9.25	0.0817		13.8	0.0831	0.26	10.3	0.1067	0.32	8.0	0.1490	0.41	5.7	0.2118	0.53	4.0	0.3159	0.68	2.7			
9.50	0.0822		13.7	0.0839	0.27	10.2	0.1078	0.32	8.0	0.1505	0.42	5.7	0.2137	0.54	4.0	0.3180	0.68	2.7			
9.75	0.0827		13.6	0.0847	0.27	10.1	0.1089	0.32	7.8	0.1519	0.42	5.6	0.2155	0.54	4.0	0.3200	0.68	2.7			
10.00	0.0833	0.22	13.5	0.0855	0.27	10.0	0.1099	0.33	7.7	0.1534	0.42	5.6	0.2174	0.54	3.9	0.3220	0.69	2.6			
10.25	0.0838	0.22	13.4	0.0863	0.27	9.9	0.1110	0.33	7.7	0.1548	0.43	5.5	0.2192	0.55	3.9	0.3239	0.69	2.6			
10.50	0.0844	0.22	13.3	0.0871	0.27	9.8	0.1120	0.33	7.6	0.1562	0.43	5.5	0.2210	0.55	3.9	0.3258	0.69	2.6			
10.75	0.0849	0.22	13.2	0.0878	0.27	9.7	0.1131	0.33	7.6	0.1577	0.43	5.4	0.2229	0.56	3.8	0.3276	0.69	2.6			
11.00	0.0855	0.22	13.0	0.0886	0.28	9.6	0.1141	0.33	7.5	0.1591	0.44	5.4	0.2247	0.56	3.8	0.3293	0.69	2.6			
11.25	0.0860	0.22	12.9	0.0893	0.28	9.6	0.1152	0.34	7.4	0.1605	0.44	5.3	0.2264	0.56	3.8	0.3311	0.69	2.6			
11.50	0.0865	0.21	12.8	0.0901	0.28	9.5	0.1162	0.34	7.3	0.1619	0.44	5.3	0.2282	0.56	3.7	0.3327	0.69	2.6			
11.75	0.0871	0.21	12.7	0.0908	0.28	9.4	0.1173	0.34	7.3	0.1633	0.44	5.2	0.2299	0.57	3.7	0.3343	0.70	2.5			
12.00	0.0876	0.21	12.6	0.0915	0.28	9.3	0.1183	0.34	7.2	0.1647	0.45	5.2	0.2317	0.57	3.7	0.3359	0.70	2.5			
12.25	0.0882	0.21	12.5	0.0921	0.28	9.3	0.1193	0.35	7.2	0.1660	0.45	5.1	0.2334	0.57	3.7	0.3374	0.70	2.5			
12.50	0.0887	0.21	12.4	0.0928	0.29	9.2	0.1204	0.35	7.1	0.1674	0.45	5.1	0.2351	0.58	3.6	0.3390	0.70	2.5			
12.75	0.0892	0.21	12.3	0.0935	0.29	9.1	0.1214	0.35	7.0	0.1688	0.45	5.1	0.2368	0.58	3.6	0.3404	0.70	2.5			
13.00	0.0897	0.21	12.3	0.0942	0.29	9.1	0.1224	0.35	7.0	0.1702	0.46	5.0	0.2385	0.58	3.6	0.3418	0.70	2.5			
13.25	0.0903	0.21	12.1	0.0948	0.29	9.0	0.1235	0.36	7.0	0.1715	0.46	5.0	0.2401	0.58	3.6	0.3432	0.70	2.5			
13.50	0.0908	0.21	12.1	0.0955	0.29	8.9	0.1245	0.36	6.9	0.1729	0.46	4.9	0.2418	0.59	3.5	0.3445	0.70	2.5			
13.75	0.0913	0.21	12.0	0.0961	0.29	8.8	0.1255	0.36	6.8	0.1742	0.46	4.9	0.2434	0.59	3.5	0.3458	0.70	2.5			
14.00	0.0919	0.21	11.9	0.0967	0.30	8.8	0.1265	0.36	6.8	0.1756	0.47	4.9	0.2450	0.59	3.5	0.3471	0.70	2.5			
14.25	0.0924	0.21	11.8	0.0973	0.30	8.8	0.1275	0.36	6.7	0.1769	0.47	4.8	0.2467	0.60	3.4	0.3483	0.70	2.5			
14.50	0.0929	0.21	11.7	0.0979	0.30	8.7	0.1286	0.37	6.6	0.1783	0.47	4.8	0.2483	0.60	3.4	0.3495	0.70	2.4			
14.75	0.0934	0.21	11.6	0.0985	0.30	8.7	0.1296	0.37	6.6	0.1796	0.47	4.8	0.2498	0.60	3.4	0.3507	0.70	2.4			
15.00	0.0940	0.21	11.5	0.0991	0.30	8.6	0.1306	0.37	6.5	0.1810	0.48	4.7	0.2514	0.60	3.4	0.3518	0.70	2.4			
15.25	0.0945	0.21	11.5	0.0997	0.30	8.6	0.1316	0.37	6.5	0.1829	0.48	4.7	0.2530	0.61	3.4	0.3530	0.70	2.4			
15.50	0.0950	0.21	11.4	0.1003	0.30	8.5	0.1326	0.38	6.4	0.1846	0.48	4.7	0.2545	0.61	3.4	0.3541	0.71	2.4			
15.75	0.0955	0.21	11.3	0.1009	0.31	8.5	0.1336	0.38	6.4	0.1862	0.48	4.6	0.2561	0.61	3.3	0.3551	0.71	2.4			
16.00	0.0960	0.21	11.2	0.1014	0.31	8.4	0.1345	0.38	6.3	0.1876	0.49	4.6	0.2576	0.61	3.3	0.3562	0.71	2.4			
16.25	0.0966	0.21	11.1	0.1020	0.31	8.4	0.1355	0.38	6.3	0.1890	0.49	4.5	0.2592	0.61	3.3	0.3574	0.71	2.4			
16.50	0.0971	0.21	11.1	0.1025	0.31	8.3	0.1365	0.39	6.3	0.1899	0.49	4.5	0.2607	0.62	3.3	0.3586	0.71	2.4			
16.75	0.0976	0.21	11.0	0.1031	0.31	8.3	0.1375	0.39	6.2	0.1904	0.49	4.5	0.2622	0.62	3.3	0.3597	0.71	2.4			
17.00	0.0981	0.21	10.9	0.1037	0.31	8.2	0.1384	0.39	6.2	0.1915	0.50	4.5	0.2637	0.62	3.2	0.3601	0.71	2.4			
17.25	0.0986	0.21	10.9	0.1042	0.31	8.2	0.1394	0.39	6.1	0.1928	0.50	4.4	0.2652	0.62	3.2	0.3610	0.71	2.4			
17.50	0.0991	0.21	10.8	0.1048	0.31	8.1	0.1404	0.39	6.1	0.194	0.50	4.4	0.2667	0.62	3.2	0.3620	0.71	2.4			
17.75	0.0997	0.21	10.7	0.1053	0.31	8.1	0.1413	0.40	6.0	0.1954	0.50	4.4	0.2681	0.62	3.2	0.3629	0.71	2.4			
18.00	0.1002	0.26	10.6	0.1058	0.32	8.1	0.1423	0.40	6.0	0.1966	0.51	4.3	0.2696	0.63	3.2	0.3638	0.71	2.3			
18.25	0.1007	0.26	10.6	0.1064	0.32	8.0	0.1432</														

Table IV. (Revised April 1963)

Error Expectancy in Estimating S from Figure 5*

Ref Level	Number of Data Points	Range of S/K	Std Dev of Data Points	Range of Error % (One Std Dev)	Error at 15% of Ref Level, (One Std Dev)
2	50	.0476 to .0942	.0058	12.2 to 6.2	7.8**
3	50	.0566 to .1209	.0056	9.9 to 4.6	5.6
4	49	.0800 to .1663	.0049	6.1 to 2.9	3.8
5	50	.1107 to .2316	.0056	5.1 to 2.4	3.1
6	49	.1581 to .3088	.0061	3.9 to 2.0	2.4
7	50	.2423 to .3879	.0221	9.1 to 5.7	6.3**

*Refer to Figure 5 of Report DPS-657 August 1962.

**The error at 15% of reference level for the revised levels 2 and 7 is greater than that of Table III, Report DPS-657 because there were insufficient data points in Table III, Report DPS-657 to adequately describe the conditions.

Table V.

Error Expectancy of Estimating S for Various Types of Data

Type of Data	Error Expectancy (%)*	Range of Error (%)*	Number of Samples of Data
a) On-board gear	5.20	0.00 to 33.33	50
b) Rate gyro	4.20	0.00 to 19.01	69
c) Strain gage	3.99	0.00 to 16.67	50
d) Filtered	4.91	0.00 to 17.98	50

*Based on $\frac{\text{Calculated value} - \text{Estimated value}}{\text{Calculated Value}}$ without regard to level.

SUBMITTED:

C. R. Lee

C. R. LEE
Mathematician

APPROVED:

J. A. Tolen

J. A. TOLEN
Chief, Engineering
Laboratories

APPENDIX E

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AD Accession No.
D&PS, Aberdeen Proving Ground, Maryland
ROAD SHOCK AND VIBRATION ENVIRONMENT
FOR A SERIES OF WHEELED AND TRACK-LAYING
VEHICLES H. T. Cline

Report No. DPS-999, June 1963
Unclassified Report

The road shock and vibration environment created by four wheeled and five track-laying vehicles was measured on eight test courses at speed increments of approximately 4 mph. The magnetic-tape data were processed through a special-purpose computer which determined the amplitude-probability distribution and spectral density. The resultant data have been catalogued in a form which will provide a base line for the design of equipment to be transported on automotive vehicles.

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